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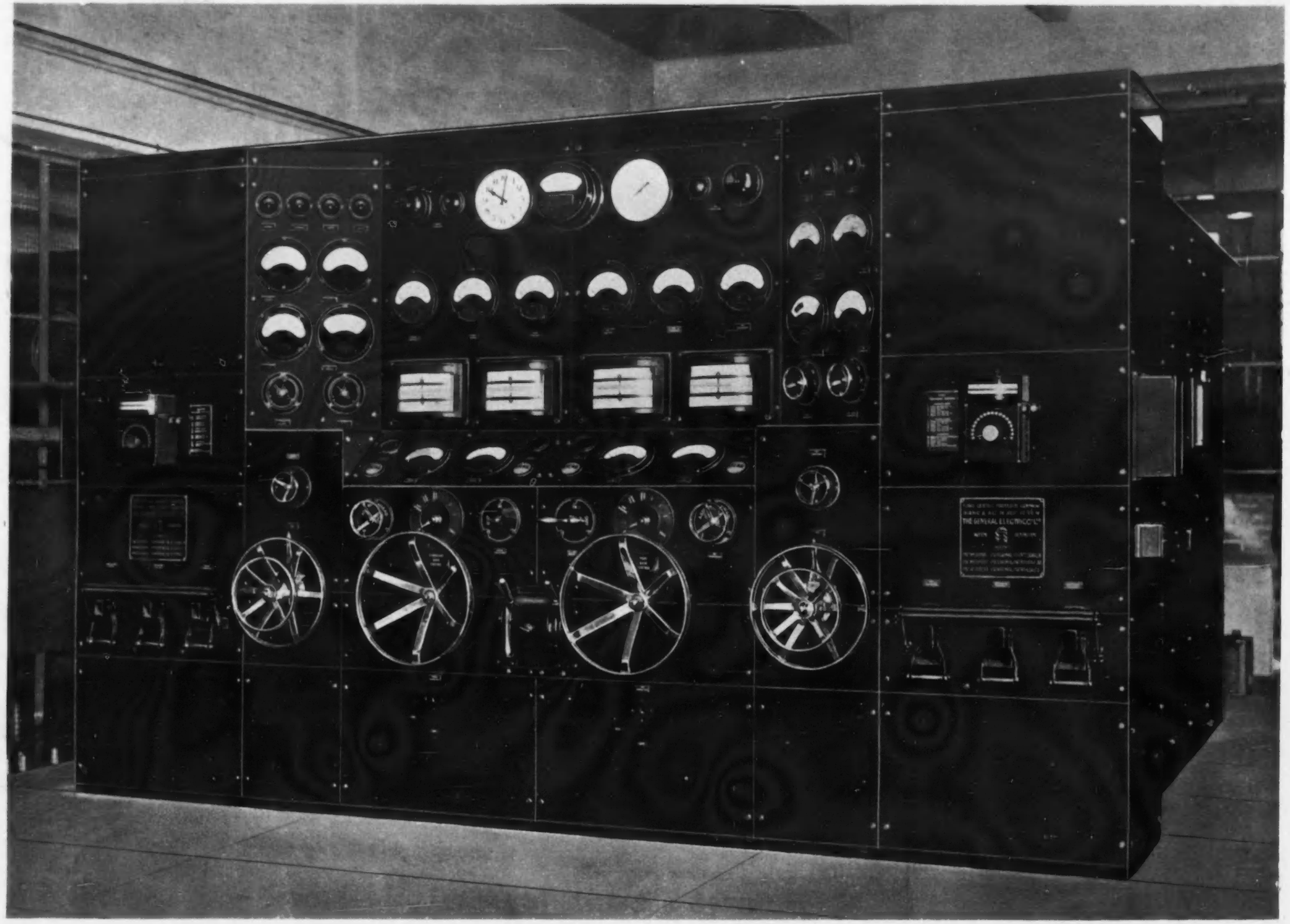

PROPULSION CONTROL SWITCHBOARD FOR THE "QUEEN OF BERMUDA."
A view taken during erection of the 3,000 volt 3-phase 50 cycle cubicle switchboard which has been installed on the "Queen of Bermuda."

G.E.C. Journal

VOL. IV. FEBRUARY, 1933. No. 1.

Electrical Progress and Development during 1932.

By H. W. RICHARDSON, B.Sc., M.I.E.E.
Editor of the "G.E.C. Journal."

THE third year of economic depression has led inevitably to most difficult conditions in industry. Yet in spite of the continued set-back to the normal development of trade, the electrical industry has maintained a sound front as a result of the steps taken to conserve its resources. The strength thus acquired will become evident when the upward tendency, already visible, gathers momentum.

Whatever decrease there may have been in commercial opportunity, there has been no lack of technical achievement. One branch of applied electricity in which great progress has to be recorded is that concerned with illumination; the rapid advance in lighting by means of discharge tubes is shown in a subsequent article in this issue.

The mercury arc rectifier is attracting more and more attention, and some important mercury arc rectifier installations have been completed during the year. Reference should also be made to the largely increased use of the photocell for industrial purposes as providing one of the features of electrical progress in 1932.

In many other directions advances have been made and it is the purpose of this article to outline the more important aspects of the work performed by the General Electric Co., Ltd., during the past year, the paragraphs which immediately follow being devoted to the results of activities in the company's Research Laboratories at Wembley.

DISCHARGE TUBES.

The developments in hot cathode tubes have proceeded along three main lines. The first includes red, blue and green tubes suitable for coloured floodlighting. These tubes provide coloured light with a far greater efficiency than do incandescent lamps combined with filters. In this same class come decorative units combining coloured hot cathode tubes with incandescent lamps. These will provide novel units for general lighting purposes. Another type of lighting fitting, comprising hot cathode tubes only, is being developed; this unit is also designed for general illumination. The tubes are hidden behind sheets of opal glass. The colour of the light emitted is pleasant, and good colour-rendering is obtained.

The second main advance has consisted in the development of a new type of discharge tube which promises to be suitable for street lighting, particularly for large and important thoroughfares. The efficiency of these tubes is high; a 400 watt tube gives about 40 lumens per watt and under laboratory conditions still more. At the moment, the colour rendering of objects illuminated by it is not quite so good as desired, but methods are being explored to improve this. A public road at Wembley was illuminated with these lamps on June 22nd, 1932, and the installation has since been placed on a permanent basis.

The third development is the sodium lamp. In

this case, the colour is not good but the lamp appears to be suitable for the illumination of arterial or country roads where there are few pedestrians, and the illumination required is low and good colour discrimination is not of great importance. These lamps can be made in units of about 80 or 100 watts and the efficiency is extremely high, values of 70 lumens per watt having been attained in the Laboratories.

As a result of these developments the tubes are now nearing the stage of commercial production.

VALVES.

(a) Transmitting Valves.

A new water-cooled transmitting valve has been developed which is far larger than any valve of this type so far made. It is in fact the largest sealed-off valve in existence; operating under telegraphic conditions at 20 kV, it can deal with an input of 500 kW. A photograph of the valve is reproduced at fig. 1. The anode has a diameter of 8 inches, while the overall length of the valve is about 45 inches. The weight is 75 lbs.

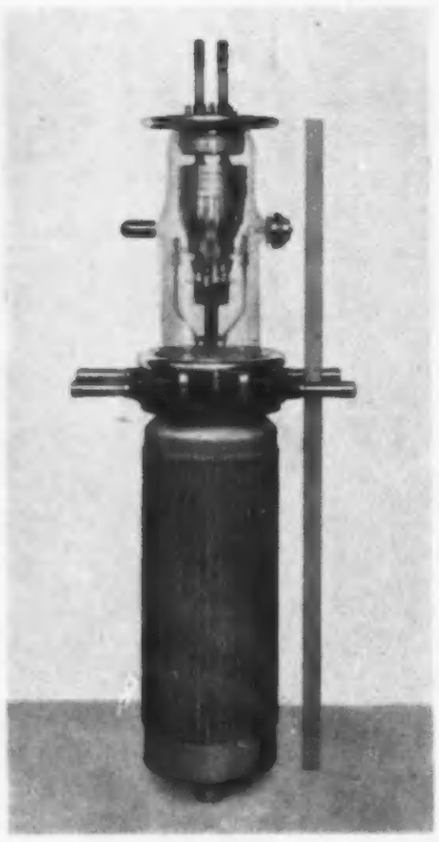

Fig. 1.—500 kW water-cooled transmitting valve, the largest of its type in existence.

In order to allow the anode to dissipate the large amount of energy necessary, its surface has been ribbed, thereby doubling the available cooling area.

The following are some of the electrical characteristics of the valve.

Filament voltage ..	..	=	32 V.
Filament current ..	..	=	460 A.
Emission current ..	..	=	100 A.
(90 per cent saturation)			
Maximum anode loss	..	=	160 kW.
Maximum anode volts	..	=	20 kV.
Amplification factor	..	=	45
Mutual conductance	..	=	50 mA/V.

(b) E.H.T. Rectifiers.

Considerable progress has been made in the design of valves for the rectification of extra high tension alternating current of 120 kV and upwards.

Production of the former standard types, E.H.T.3C rated at 125 kV reverse voltage, and E.H.T.3A at 150 kV, has expanded, and the extreme rarity of failures during a year's operation shows that a very high standard of reliability has been attained. The current capacity of these types has also been doubled.

In new types of the same voltage ratings having an air-cooled anode as part of the envelope (as illustrated in fig. 2), the current capacity has again been doubled, and the capacity to withstand over-loads due to short circuiting the load resistance has been considerably increased.

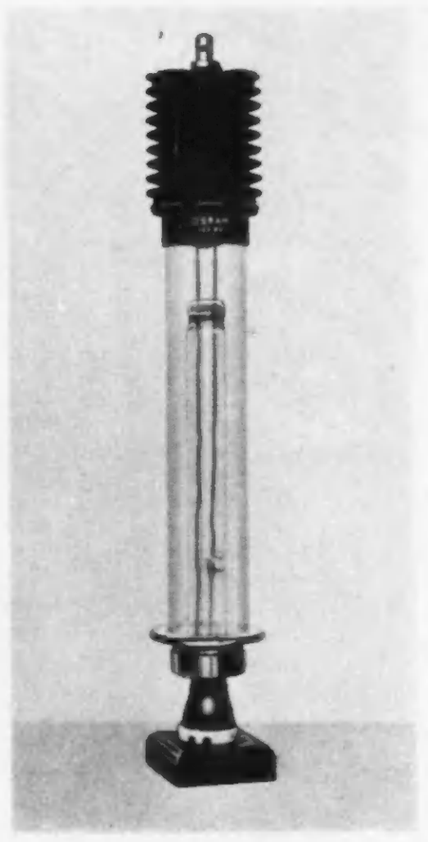

Fig. 2.—E.H.T. air-cooled rectifying valve.

The E.H.T.3 series of glass bulb rectifiers has also been extended by the E.H.T.4 rated at 200 kV reverse voltage.

GASFILLED RELAYS.

The theory, design and application of the gas-filled relay were discussed in an article which appeared in the issues of this Journal for May and August, 1932. The G.T.1, a small type of gasfilled relay recently introduced by the G.E.C., is already finding numerous applications such as lift control and other work where a sensitive relay is required.

Development of the larger types is continuing, notably in the case of a tube having a power handling capacity about one hundred times as great as that of the type G.T.1. It is expected that the importance of this tube in electrical engineering will far outweigh that of the smaller pattern.

PHOTOMETRY.

Further progress has been made in the development of photoelectric photometers. The design of valve amplifiers for this purpose has been considerably improved and the construction simplified, resulting in increased accuracy in both precision and commercial photometry.

A photoelectric photometer which indicates the efficiency of the lamp under test on a scale calibrated directly in lumens per watt has been in continuous use in the Osram Lamp Factory at Wembley for the last six months. Lamps can be measured in this photometer at five times the speed possible on the commercial visual photometers which it superseded. Another photoelectric photometer which incorporates the latest amplifier design is being built by the Osram Lamp Works in collaboration with the Research Laboratories for measuring the lumens of 15 to 150 watt lamps to a high order of accuracy.

An experimental precision portable photoelectric photometer has been made for measuring street lighting illumination values as low as 0.1 ft. candle. This is, at present, undergoing tests under service conditions.

With the development of gas discharge tubes has arisen the demand for methods of determining their light output. The comparison of coloured light sources with the ordinary white light standards is difficult enough, but the problem is further complicated by the fact that the ordinary standards produce a continuous spectrum while the spectrum of the discharge tubes consists of a number of lines. Extensive experimental work is in progress with the object of simplifying the photometry of these tubes, both for precision and commercial purposes.

HEATING OF LEADS TO LIGHTING FITTINGS.

Considerable attention is being paid at the present time in the Research Laboratories to the heating of the leads to lighting fittings. This is a matter of great importance to manufacturers of fittings, as well as to cable makers, and it is on this account being investigated by the Electrical Research Association.

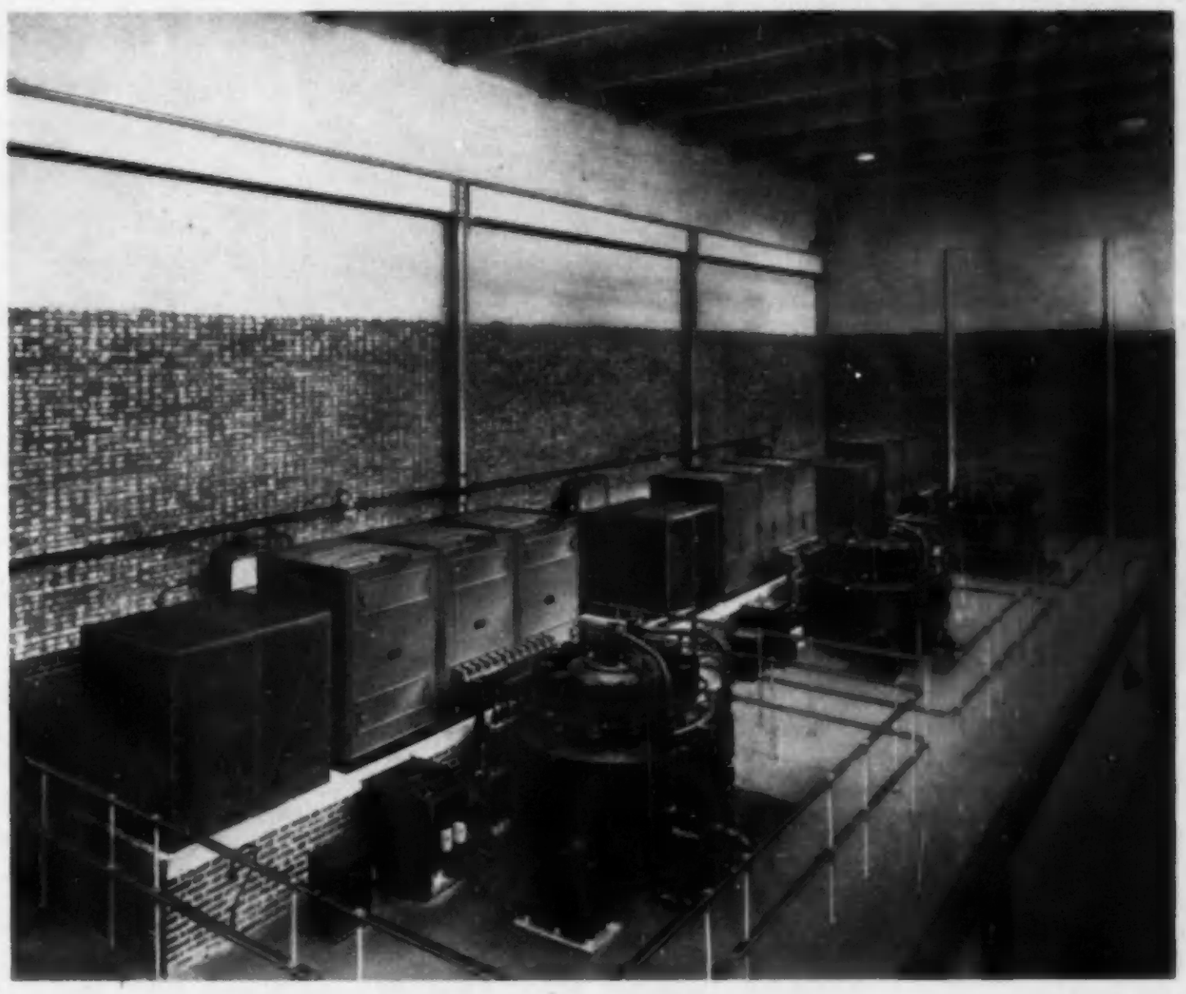

Fig. 3.—Three 1,500 kW G.E.C. mercury arc rectifier equipments installed in the Chiswick Park Sub-station of the London Electric Railway.

It has been known for a long time that leads to lighting fittings operate at temperatures much above that at which the rubber insulation of the type now in use can be expected to withstand some of the rough usage it meets in service.

The experimental investigation by the Electrical Research Association of the conditions prevailing when the lamp is burning will probably indicate that it may be possible so to design fittings as greatly to reduce the temperature of the leads.

Investigations with this object in view are therefore in hand to follow up the work of the Association.

METALLURGY.

The mechanical properties both at ordinary and high temperatures of nickel wire such as is used for wireless valve filaments have been investigated, and it has been found that small additions of other

elements have a marked effect on these properties. In some cases these additions also improve the emission characteristics of the nickel wire.

Other branches of the work are concerned with electrical heating apparatus. For electric hot plates as at present manufactured, a good quality grey cast iron is satisfactory. For plates which have to operate at a higher temperature, however, a cast iron with greater heat resisting properties is required. In this connection work has been mainly directed towards the development of suitable tests and the testing of commercial irons which are claimed to be suitable for this purpose.

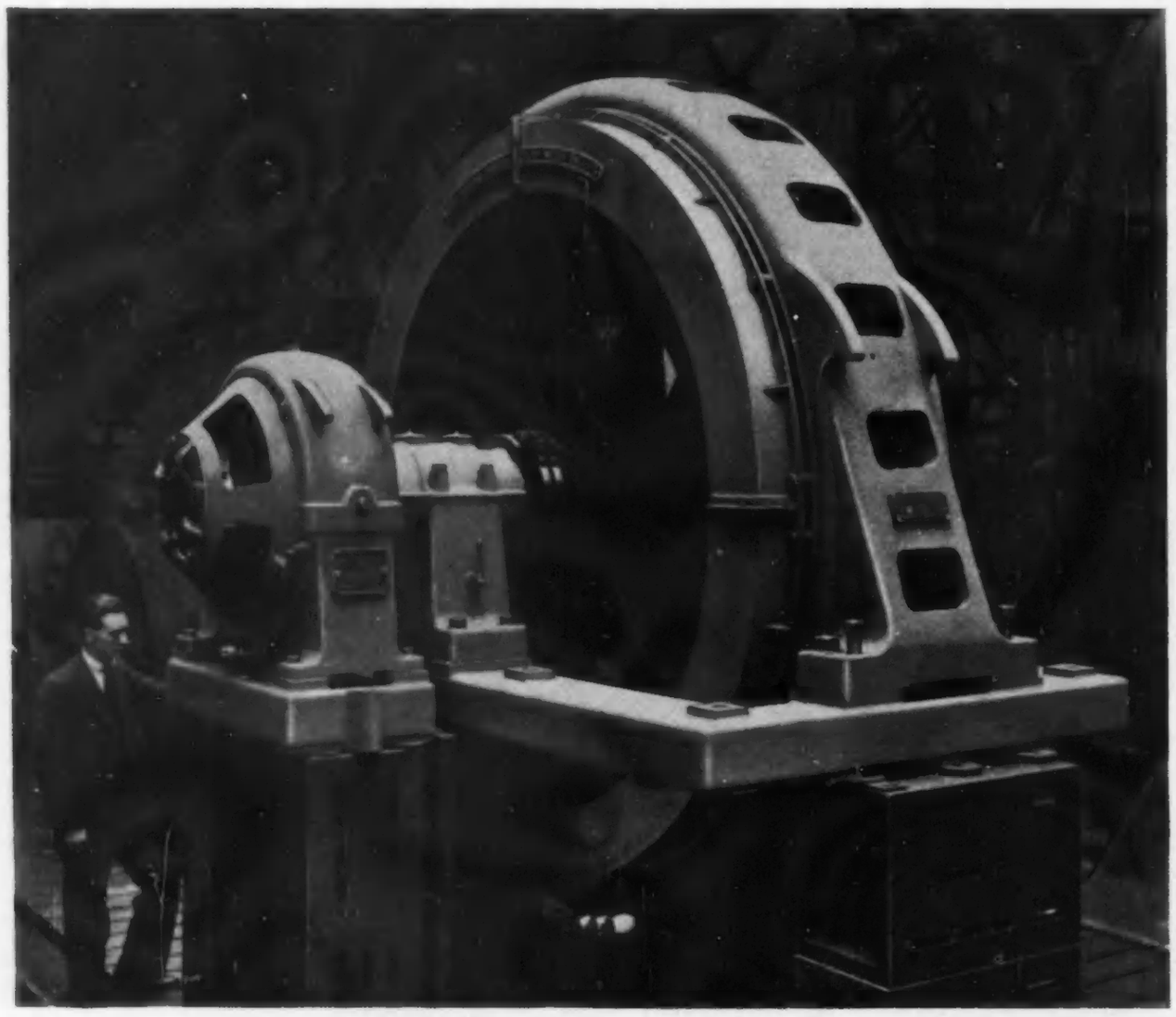

Fig. 4 (above)—1500 kW alternator for Macao; it will be driven by a Fraser & Chalmers Diesel engine.

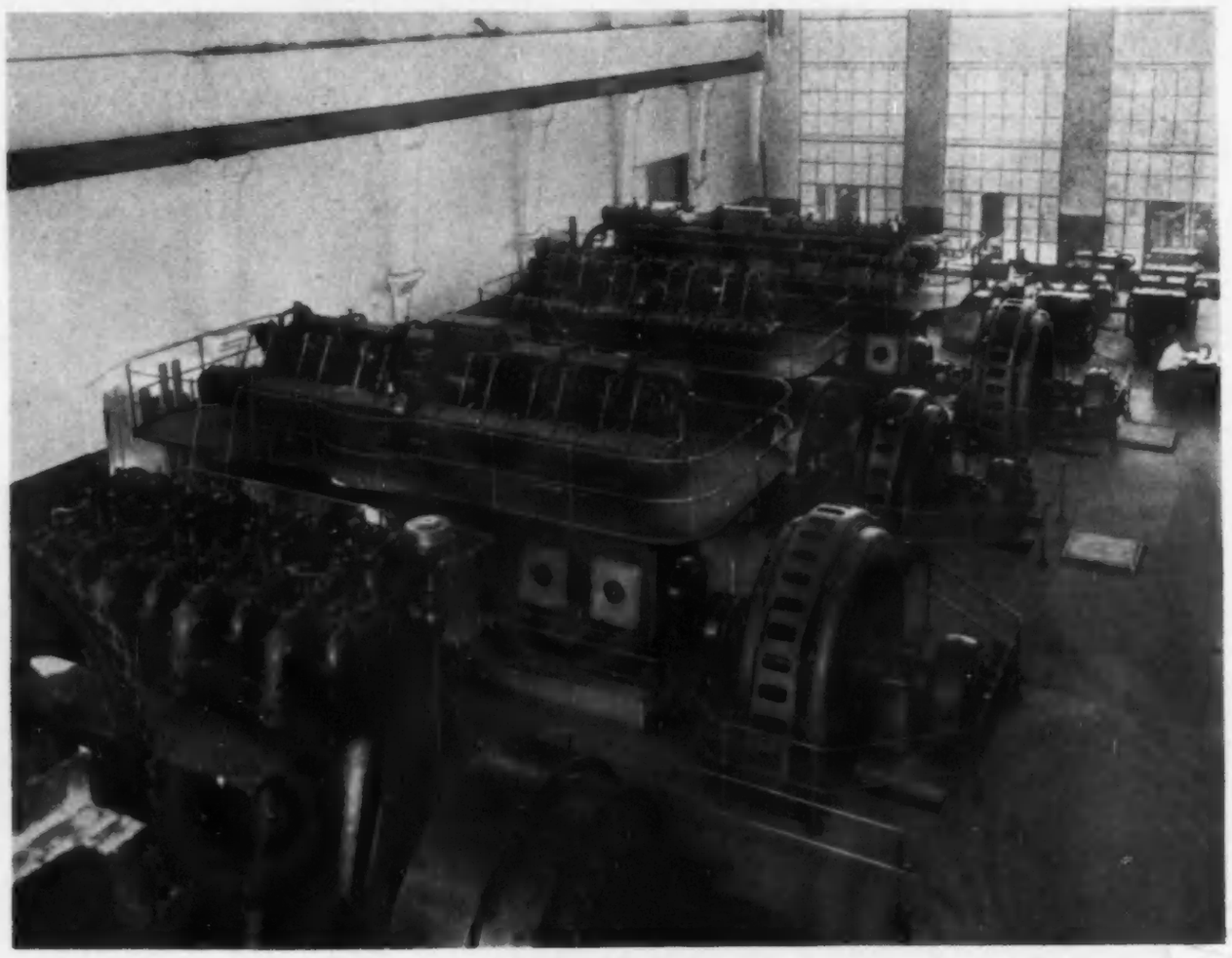

Fig. 5 (right)—Two 6-cylinder and one 4-cylinder Fraser & Chalmers Diesel engines driving two 1500 kW and one 750 kW G.E.C. generators at the Telavir power station of the Palestine Electric Corporation.

The bright annealing of metals is becoming increasingly important, and whereas the majority of metals and alloys can be bright annealed with success, brass and certain other zinc bearing alloys present peculiar difficulties, more particularly because of the ease with which zinc volatilizes. This problem has been investigated, and a method developed for the bright annealing of fine brass wire, such as is used for weaving into cloth, both in pots and by a continuous process. This work is being extended to strip and other heavier sections.

GLASS AND REFRACTORIES.

Further improvements have been made in glasses for various kinds of discharge tubes, some of which are in everyday commercial use. For hot cathode tubes glasses of very special composition are required and in this connection experimental and development work is proceeding very rapidly. Glasses have been produced suitable for use in connection with ultra-violet ray lamps. The work on refractories for glass-melting pots has resulted in a marked improvement in the life of the pots and in the quality of glass obtained from them.

POWER PLANT.

The demand for power plant of large capacity has been restricted of late, due to world conditions. Several sets possessing features of interest have, however, been constructed, and either are in service or will shortly be placed in commission. A 20,000 kW turbo-alternator for the L.M.S. Railway is a case in point, as it is one of the largest generating units yet constructed for purely traction service. The completion of fifteen mercury arc rectifiers also for traction supply, is a noteworthy event. The principal features of these rectifiers (fig. 3), and

the advances made in the design of this class of plant will be dealt with fully in an article which is to appear in the next issue of the *G.E.C. Journal*. The demand for other types of converting plant for railway electrification schemes is evidenced by the completion of ten 1,500 kW rotary converters for the Metropolitan Railway.

The largest motors built during the year are those for the Q.T.E.V. "Queen of Bermuda," a sister ship to the Q.T.E.V. "Monarch of Bermuda," which was fully described in *G.E.C. Journal*, Vol. III, No. 1, page 31. The capacity of each of the four motors is 5,000 h.p., at a speed of 150 r.p.m. The supply for these machines is provided by two 7,500 kW turbo-alternators, while the auxiliary supply for the vessel is given by four 750 kW geared direct current turbo sets. Some further particulars of the electrification of the "Queen of Bermuda" are given in a subsequent section of this article.

Increasing use is being made of geared turbo-alternator sets in factories where a demand exists for process steam. The economies which may be effected by the employment of backpressure or passout turbines in such circumstances is discussed fully in a separate article on a later page. Power plant of this type has been manufactured—or is in progress—for several industrial undertakings in this country, representing particularly the iron and steel, the colliery and the paper industries. For one paper mill 3—5,000 kVA sets are in hand, and for another a 5,000 kW passout turbine is to drive two 2,500 kW direct current generators in tandem. Geared sets are also being manufactured for India, China, South Africa and the Federated Malay States. Another type of generator in hand for export is a 7,500 kVA vertical spindle alternator for a hydro-electric scheme in Palestine.

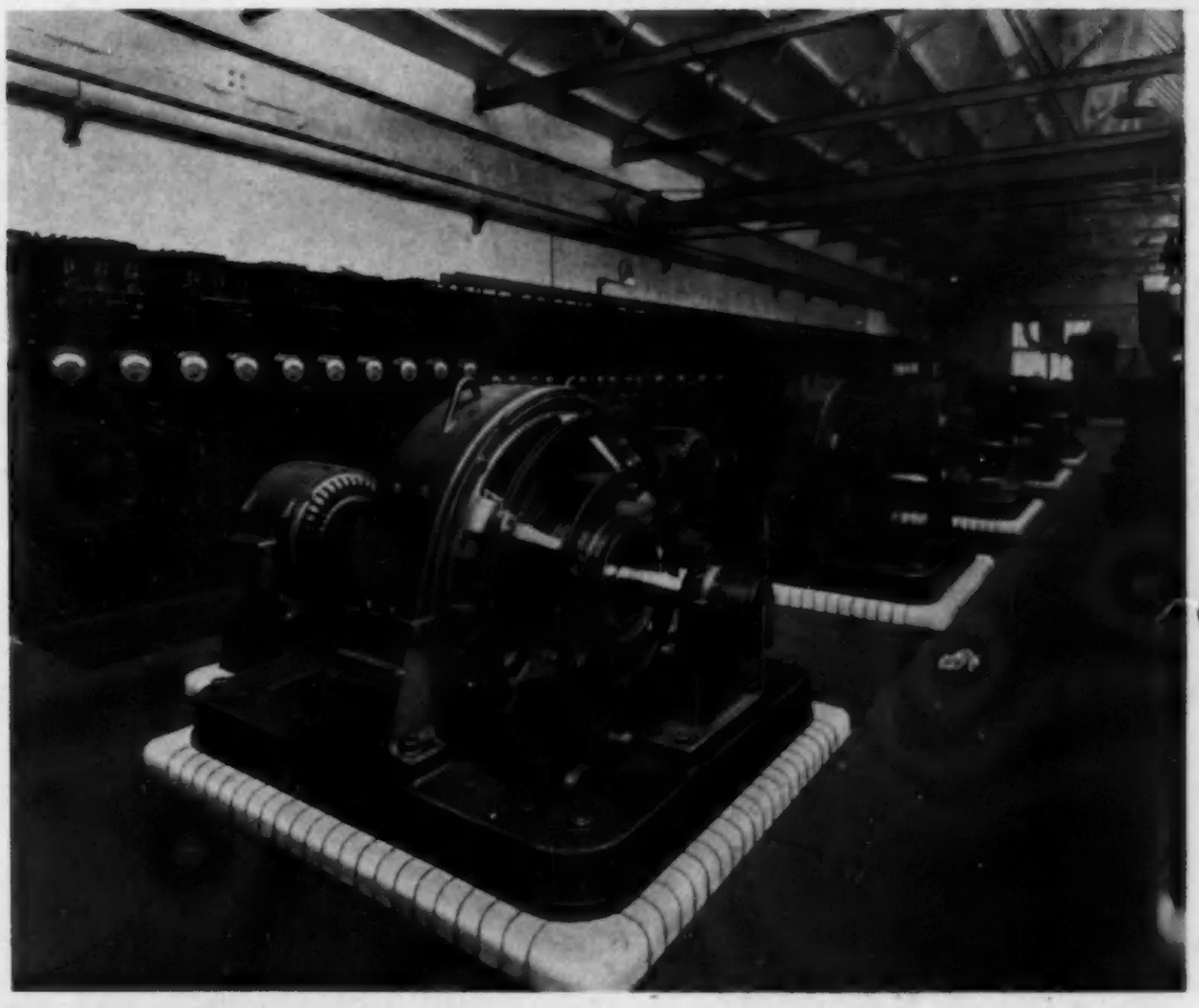

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Fig. 6 (above).—Five 350 kW rotary converters installed in the Wolseley Motor Works, Birmingham.

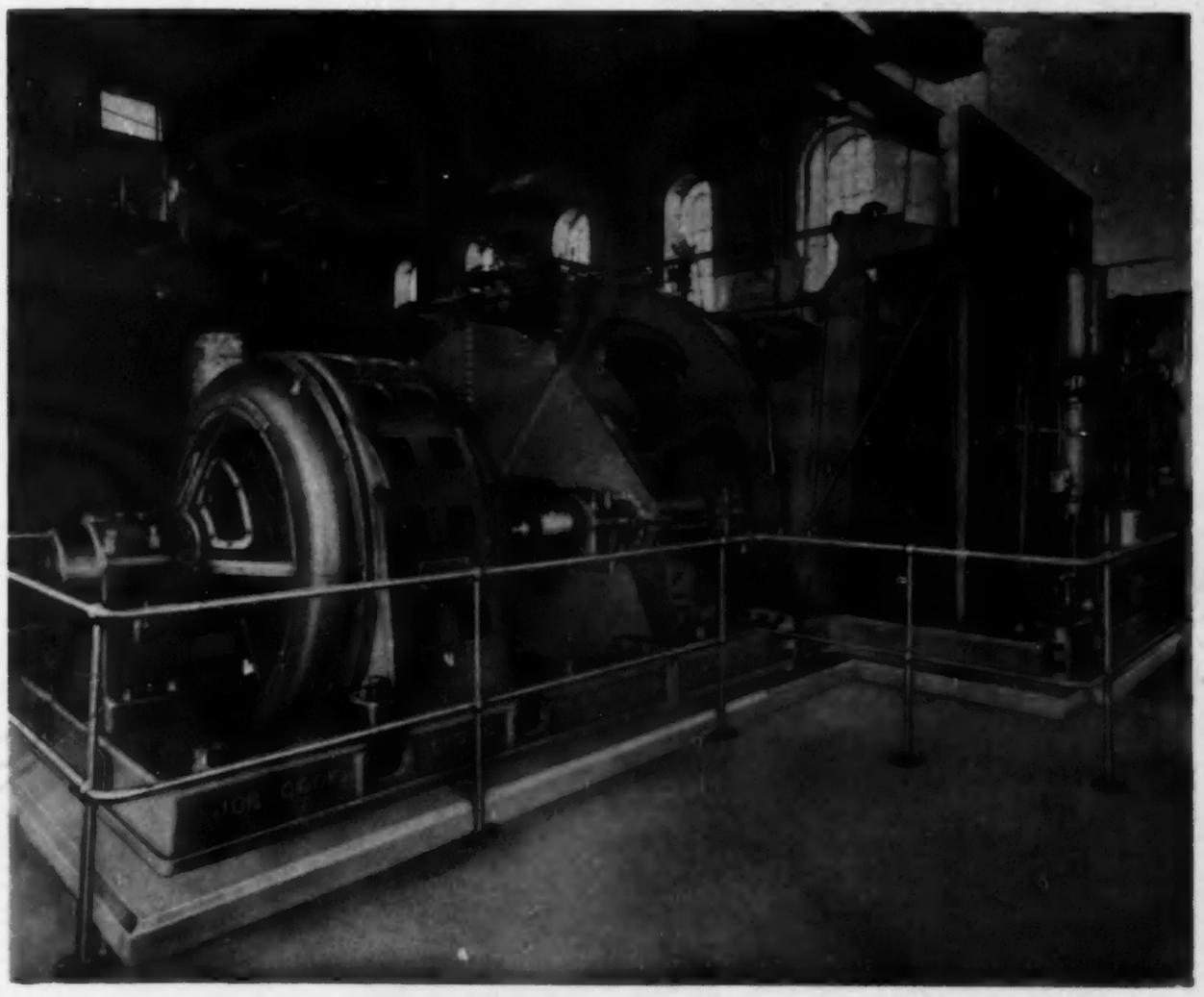

Fig. 7 (left).—1,000 h.p. A.C. winder at Usworth Colliery. This is the largest A.C. winder on the N.E. coast.

There is a growing demand for Diesel driven generating plant. Two sets of 1,500 kW output, each embodying the Fraser & Chalmers Diesel engine, afford examples. One of these, of which the alternator is illustrated in fig. 4, has been shipped to Macao. The other is for the West Cambrian Power Co.'s station at Haverford West.

There have not been many extensive schemes of industrial electrification during the past year, but some of the work passing through the shops for industrial undertakings gives an indication that in more favourable conditions, electrical equipment would

be in wide demand. Installations which are typical of modern requirements include that at the Wolseley Motor Works, Birmingham, fig. 6, where five 350 kW rotary converters and fifteen three-phase transformers have recently been taken into service. The New Consolidated Gold Mines are adding

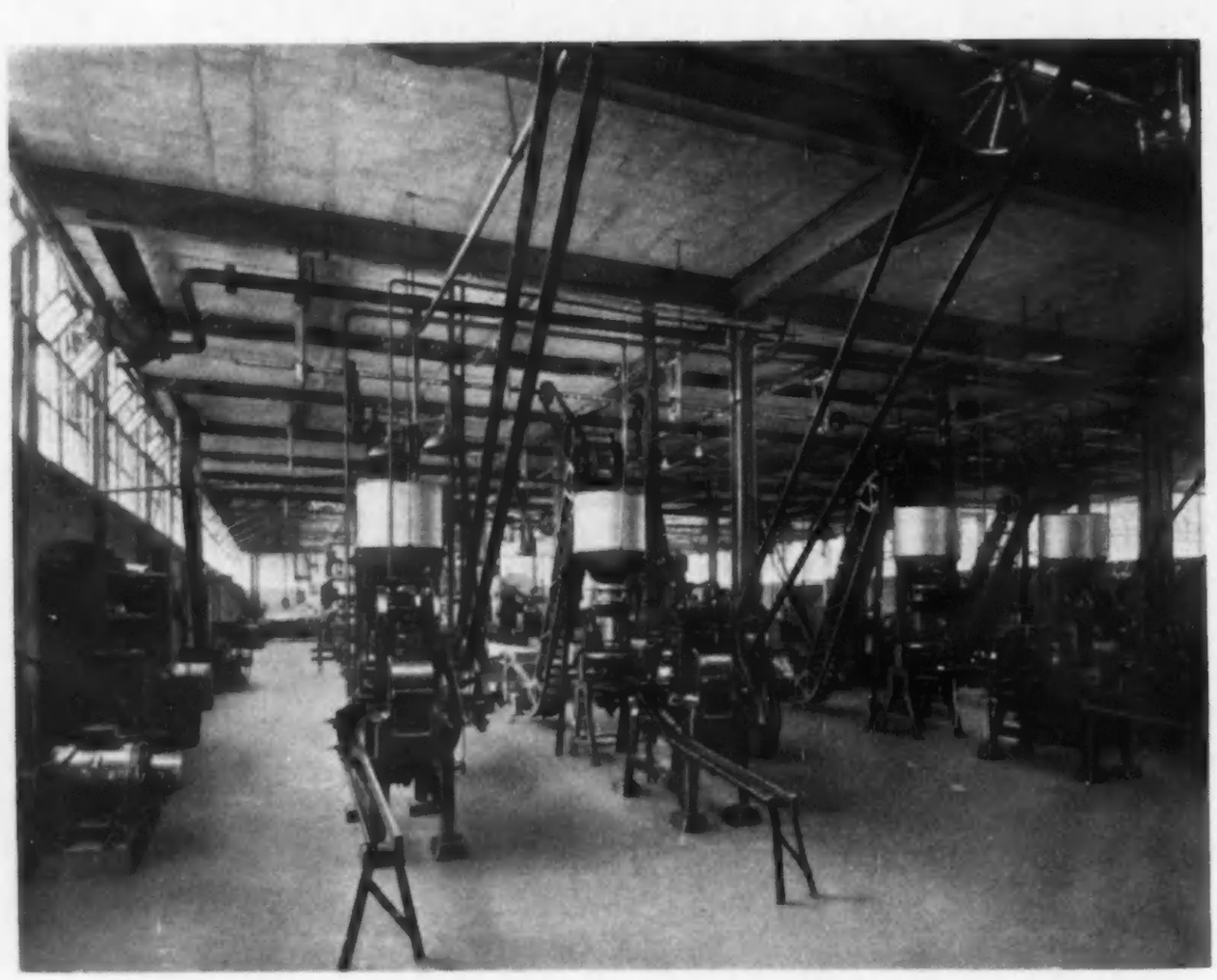

Fig. 8.—Electrically driven plant in a fruit and vegetable canning factory.

to their power plant five 800 kVA oil engine driven alternators, while at a factory in Persia a 350 kVA alternator is to be installed. Considerable extensions are being made to the plant of the Indian Copper Corporation—described in *G.E.C. Journal*, Vol. II, No. 1; a further turbo-alternator, switchgear, motors and other apparatus are being manufactured for this undertaking. Electrification on an extensive scale is being carried out by one of the largest cotton mills in India for which transformers, switchboards and motors are in progress. Another Indian textile mill is installing a considerable number of loom motors.

Winding plant is represented principally by a contract for gold mines in India and several colliery winders on the N.E. coast. The 1,000 h.p. A.C. winder, which was mentioned in *G.E.C. Journal* (Vol. III, No. 1, page 6), is in service. It is illustrated at fig. 7, and is noteworthy as the largest A.C. winder on the N.E. coast.

An industry relatively new to this country, namely that of food canning is making extensive use of electricity, which is applied to the preparation and canning of meat, fruit, vegetables, etc. A view in a factory engaged in fruit and vegetable canning is shown at fig. 8. This factory has been equipped with electrical plant for all power and lighting purposes.

Much development work has been completed in connection with the application of electricity to certain other industries, of which should be

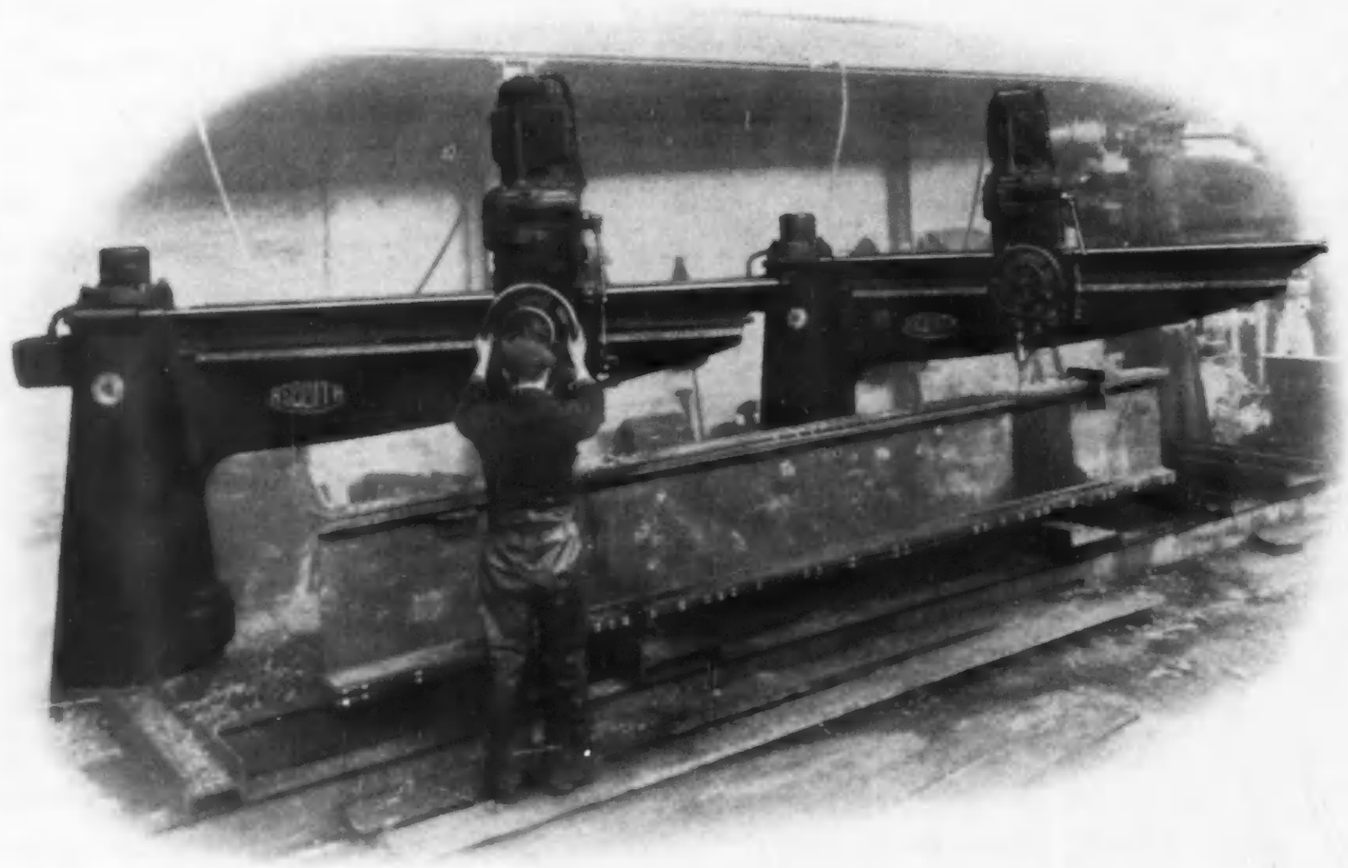

Fig. 9.—Combined drilling and tapping machine driven by A.C. motors capable of 1,200 reversals per hour.

mentioned those of cane sugar production, tea treatment, paper making and quarrying.

INDUSTRIAL MOTORS.

There has been a growing tendency to build motors for specific industrial purposes. This tendency is exemplified by a line of two speed high torque one hour rated motors, in which particular attention has been given to the characteristics required for lift duty. They are designed for a maximum speed of 700 or 900 r.p.m. and a minimum speed of 230 r.p.m. The motors are silent during starting, running and retarding; they give correct speed-torque characteristics throughout the whole cycle of lift duty.

Another example is provided by an A.C. motor recently developed to meet the requirements of a combined drilling and tapping machine, fig. 9, for use in engineering shops engaged on mass production. Such a motor has to be capable both of running continuously for drilling and also of frequent reversals with quick retardation and acceleration for tapping, the reverse motion being required for withdrawing the tap. A large number of motors of this type have been supplied. They are capable of 1,200 reversals per hour, complete acceleration from rest to full speed being obtained in a third of a second with direct-to-line starting.

Ranges of motors for driving pumps have been developed. One of these comprises high speed induction motors with outputs up to 750 h.p. at 3,000 r.p.m. A typical illustration is shown in fig. 10. Another range consists of vertical spindle motors for which there has been recently a considerable demand. In cases where power factor correction is desirable synchronous induction motors are installed, a good example of this practice being afforded by the motor shown at fig. 11.

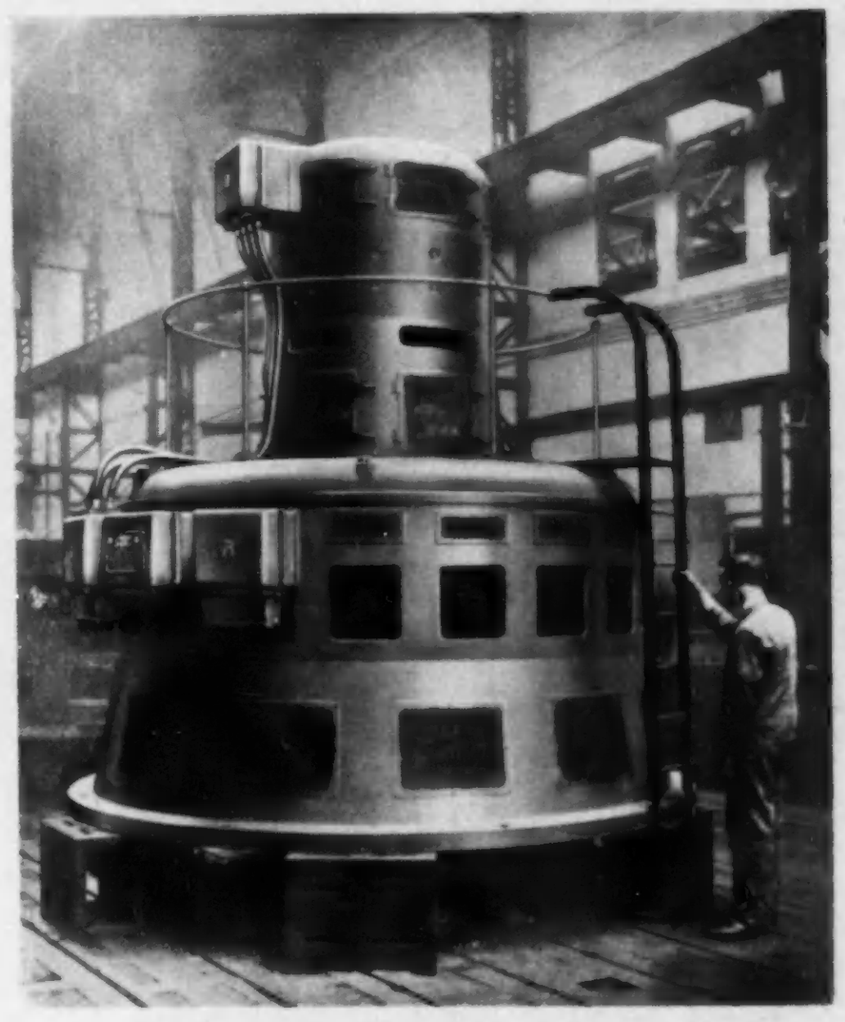

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Fig. 11.—1,200 h.p. vertical spindle synchronous induction motor, 6,600 volt, 272 r.p.m., for driving pump and giving power factor correction.

SMALL MOTOR APPLICATIONS.

The application of fractional horse power motors

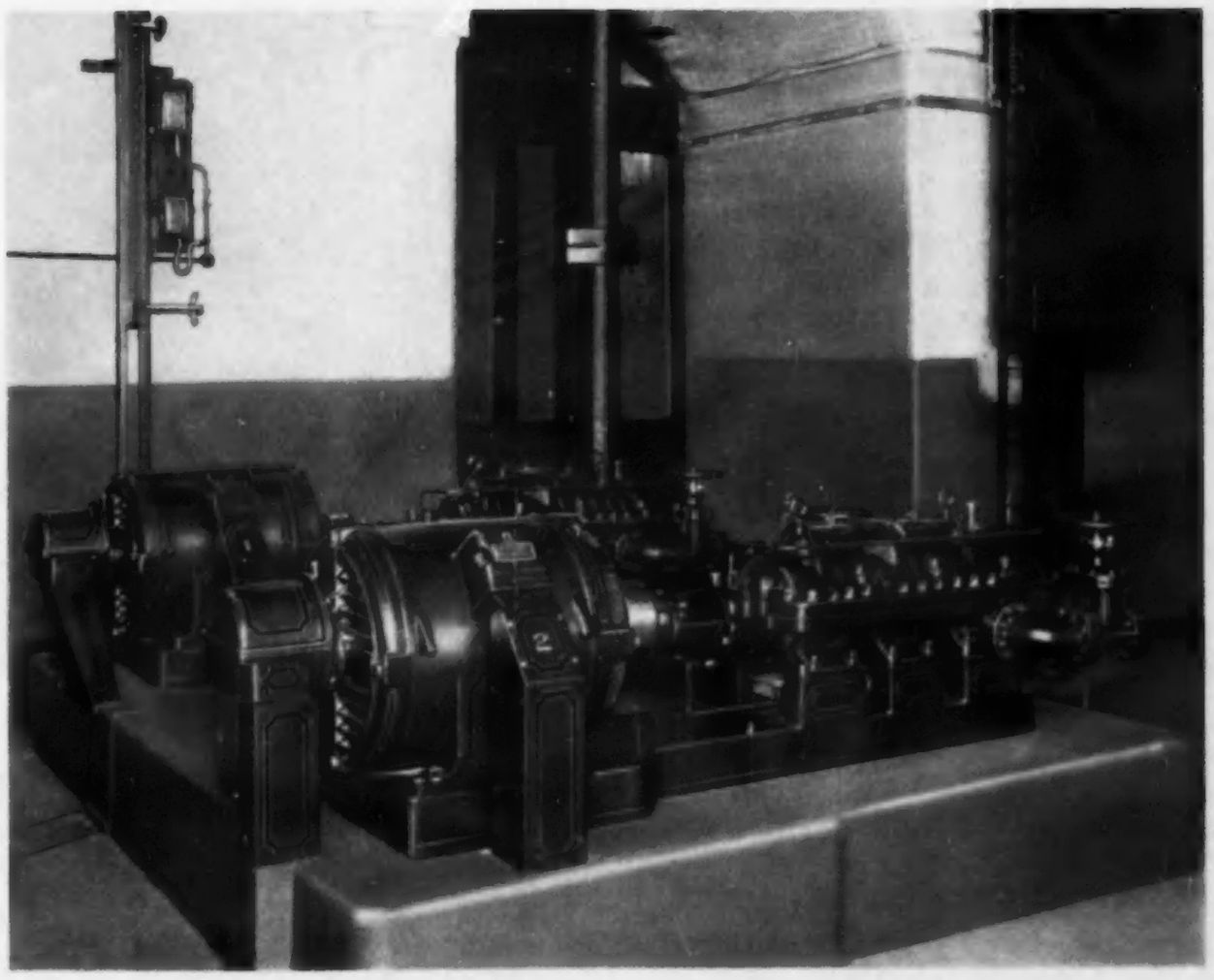

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Fig. 10.—Two 120 h.p., 3,000 r.p.m. slip ring induction motors driving high speed centrifugal pumps delivering 125 gallons of water per minute at 750 lbs. per sq. in.; automatically controlled by hydraulic accumulators.

to industrial and domestic appliances has made rapid strides. The Small Motor Works at Witton has been considerably extended in order to cater for the increased output of electric cleaners, gramophone motors, silk spinning motors, machine tool motors, motor sirens and the like. Several new developments call for brief reference.

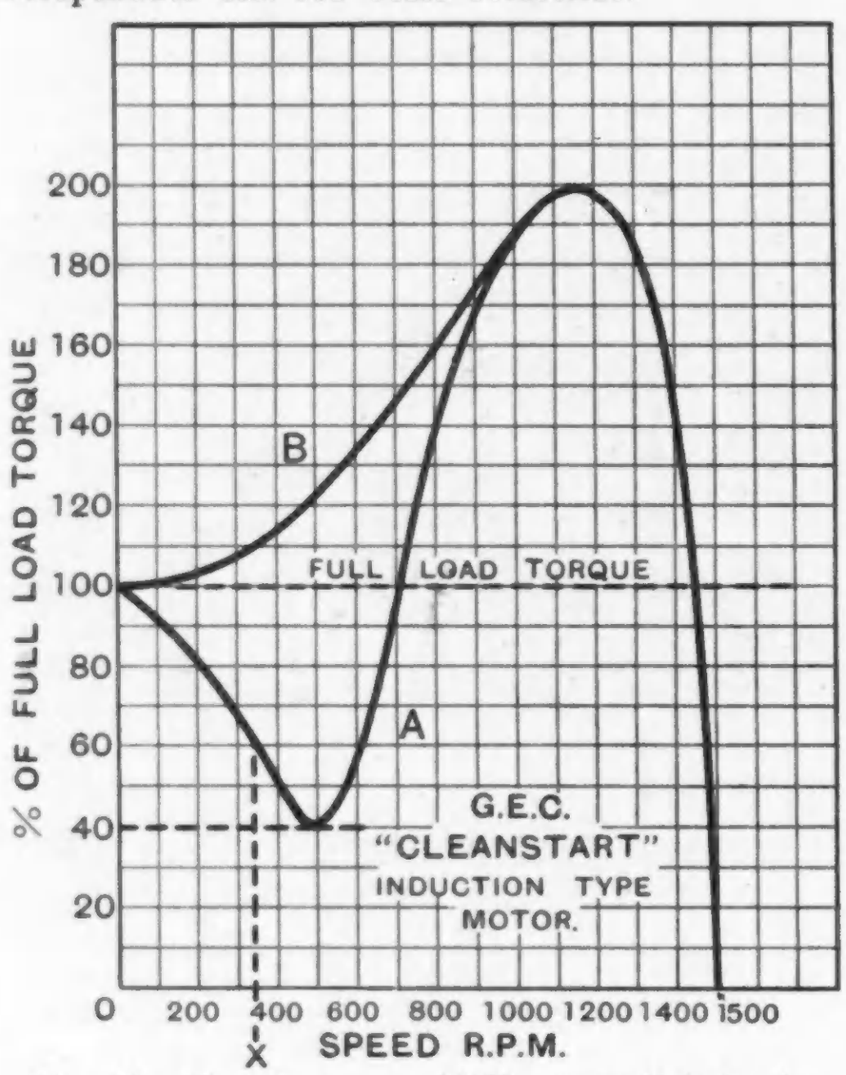

Fig. 12.—Torque curve of "Cleanstart" induction type motor.

A development of the standard type is the "Cleanstart" induction motor. The ordinary single phase squirrel cage (split phase) motor has several desirable features, principally low cost, simple construction and freedom from commutator troubles, but one drawback, which is met with in some applications, is the difficulty of starting against load. The standard split phase motor will generally start under such conditions, but it will not run up to speed, as the running-up torque is invariably lower than the static torque. The "Cleanstart" motor has been designed to overcome this disadvantage.

Curve "A" (fig. 12) shows the variation of torque with speed on a machine having a rotor of the usual construction. It will be seen that while the static torque is equal to full load torque, as the rotor begins to revolve the torque falls off to a minimum of 40 per cent of full load. Consequently such a machine will not run up against a torque in excess of 40 per cent full load. Against a torque of (say) 60 per cent of full load, it would not run up to full speed, but only to speed X.

Curve "B," shows the performance of the same machine when fitted with a "Cleanstart" rotor. In this case the torque is maintained, so that having started the machine will run up to speed.

Improvements in silk spinning motors, fig. 13, have made possible speeds up to 18,000 r.p.m., compared with the previous standard range of 6,000 to 10,000 r.p.m.

G.E.C. gramophone motors are now available for a wider range of speeds, and in addition to the standard slow speed machines, high speed machines have been made for certain types of instrument.

A gramophone record changer has been developed which operates on novel lines. It deals with eight records in succession, of either 12 in. or 10 in. diameter. The selected records are threaded over a central spindle, the peripheries being supported by three fingers raised about 3 in. from the turntable. The apparatus is then started by touching a switch, when the records automatically fall, and are played automatically. As soon as the record is finished, the pick-up head automatically rises and returns to the outward position, when the next record falls on to the turntable and is played.

The chief feature of the mechanism lies in the method of delivery to the turntable, which is accomplished by means of fixed and loose fingers, revolving about three finger supports. These fingers perform a circular motion backwards and forwards, and they are so arranged that one passes between the bottom record on the spindle, thus holding all in position, with the exception of the last record which falls on to the turntable.

Fig. 13.—Artificial silk spinning motor, 12,000/18,000 r.p.m.

The mechanism is driven by a standard gramophone motor, the various motions being given by a cam, which is arranged to make one revolution upon the completion of the record, and is then thrown out of action. The revolution of the cam effects all the movement necessary to give the required motions to the pick-up head and also to feed the records on to the turntable.

A type of motor which has attracted much attention is an "indicator" motor, based on the "Twyntorq" principle, which is capable of reproducing mechanical movement at a distance. One machine, termed the transmitter, is controlled to perform a certain restricted mechanical duty, such as the operation of a signal arm through a given angle at a required speed. One or more duplicate machines, termed "receivers," coupled electrically to the "transmitter," will exactly reproduce its rotation.

A small flameproof motor in sizes of $\frac{1}{3}$ to $\frac{1}{2}$ h.p. is being used in increasing numbers for driving petrol pumps, also in situations where gas or chemical fumes are present. This motor complies with the latest mining requirements.

Another type of motor developed is for driving large hair drying units of the helmet type. The standard hair drier is now contained in a bakelite moulding which is undoubtedly more acceptable than the nickel case previously used.

Domestic appliances embodying motors of very small output are the subject of continued progress, as exemplified by the extended range of Magnet cleaners.

ARC WELDING SETS.

An increasing number of manufacturers are employing electric welding in the production of fabricated articles and structures, and there is every evidence that its universal adoption in shipyards is a matter only of time.

In order to meet the demand for welding equipment, there has been developed at Witton Works a self contained arc welding set, fig. 14, which can be arranged for A.C. or D.C. motor, petrol, paraffin or Diesel engine drive. A number of sets are in course of production.

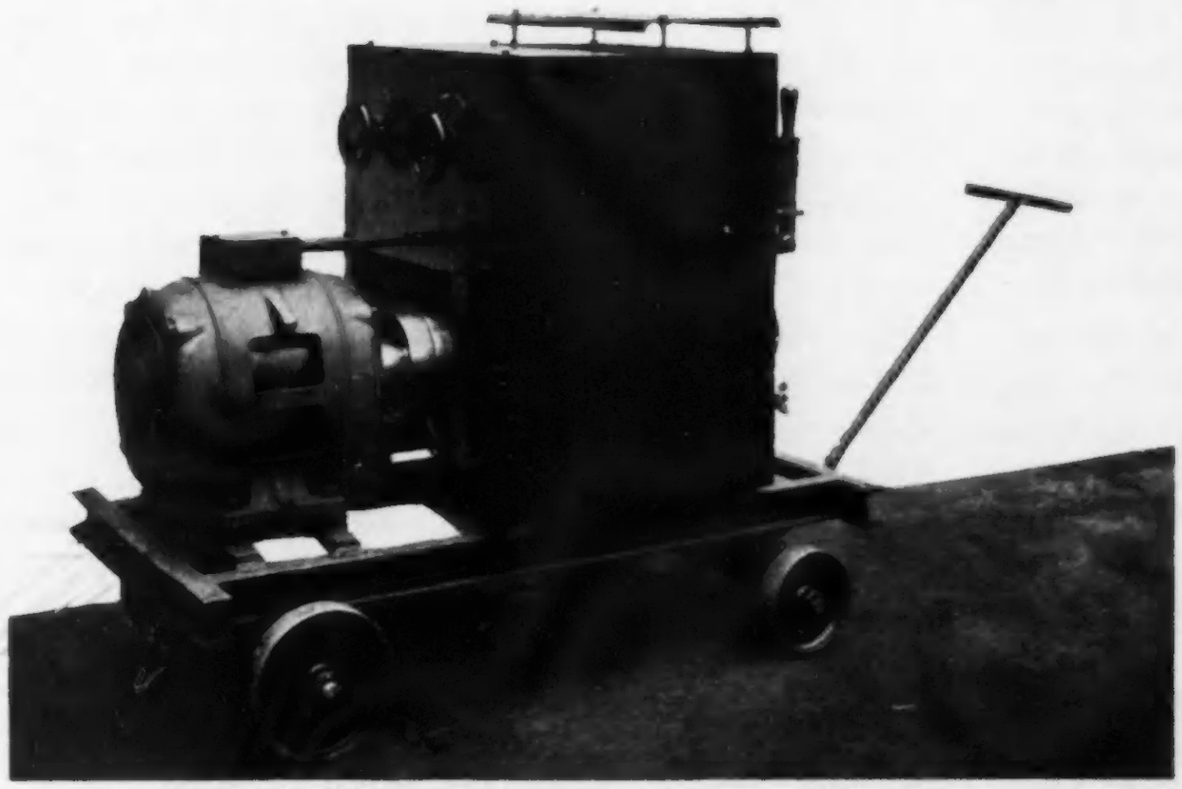

Fig. 14.—Self-contained electric arc welding set.

The capacity of the generator is 500/200 amps at 20/30 volts with a striking voltage of 65, and for normal operation no external appliances are required for stabilising the arc, the welding leads being connected direct to the appropriate terminals, which are marked to correspond with the gauge of electrode to be used. Final current adjustment is obtained by means of a field regulator. The complete unit is mounted on a fabricated bedplate, which may be converted into a portable truck by the addition of wheels and drawbar. The enclosure is suitable for protecting the essential units from falling dirt or dripping water, and for outdoor use an overhead canopy is supplied, the sides being protected with removable panels.

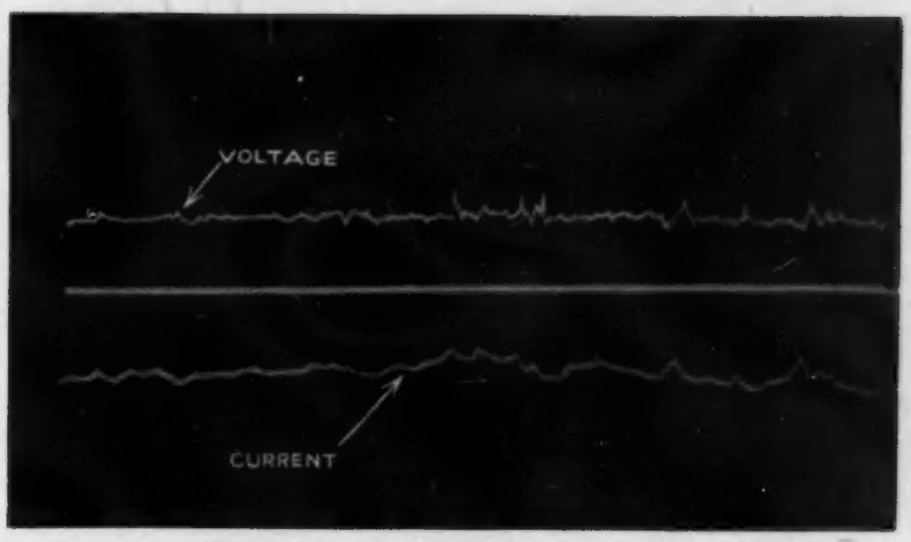

Fig. 15.—Oscillograph record of a weld joining two $\frac{1}{2}$" steel plates (time $\frac{1}{2}$ sec.)

An oscillograph record of a weld joining two $\frac{1}{2}$ in. steel plates made by a G.E.C. welding set is reproduced at fig. 15. This shows that the welding current is kept constant within extremely narrow limits during the welding operation, which is a point of the utmost importance if a reliable weld is to be ensured.

METALCLAD SWITCHGEAR.

A notable feature in switchgear practice has been the continued dominance of metalclad switchgear of the drop down type. A large number of switchboards have been completed for prominent supply undertakings with breaking capacities up to 1,500,000 kVA. A typical example of this gear is shown at fig. 16.

Much effort has been concentrated upon fundamental problems relating to the design of metalclad switchgear, resulting not only in the reduction of costs, but also in a general simplification from the point of view of operation, and of maintenance. The greatest possible measure of standardisation has been introduced; particularly does this apply to gear of medium breaking capacities, for which conditions are not so likely to vary as in the case of the higher breaking capacities.

PROTECTIVE GEAR.

The scope of the G.E.C. system of protection (McColl patents) is continually being enlarged, the flexible nature of the system having rendered it capable of successful application to a wide variety of protection problems. Several sections of the 132 kV Grid protected by standard McColl relays have been

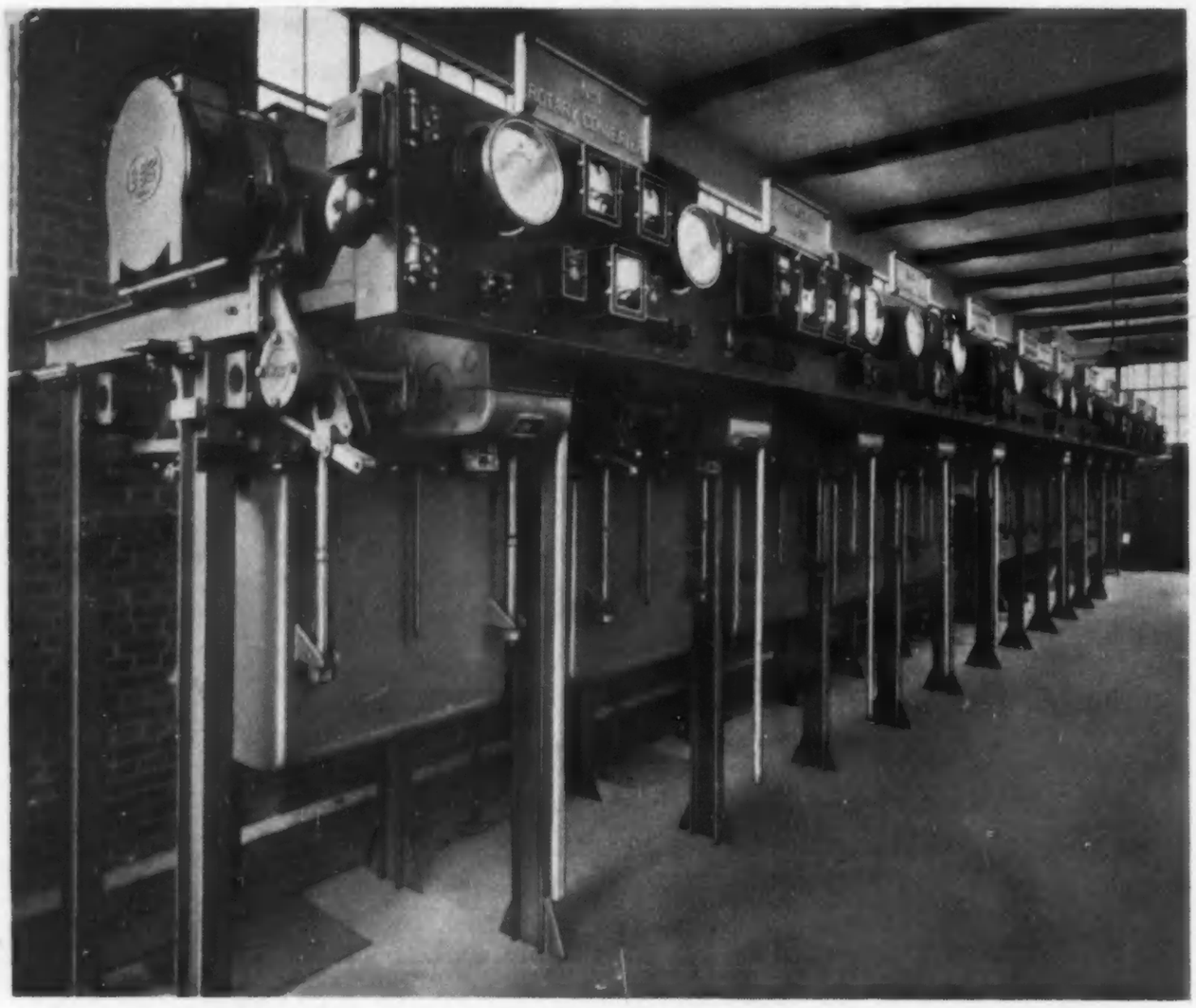

Fig. 16.—500,000 kVA, 11,000-volt metalclad switchboard at the Preston Road sub-station of the Metropolitan Railway, London.

put into commission, also the first of the 33 kV rural feeders of the Northampton Electric Supply, which is 18 miles long. In this latter instance not only was a single biassed beam relay used at each end instead of the usual three units (one unit per phase), but for the first time the pilot system consisted of only a single bare copper wire strung on the same posts that supported the feeder, and located between and equi-distant from the three main conductors. This method has been valuable in reducing the cost of the pilot to a very small figure. One of the principal objections to pilot protection of rural feeders in the past has been the first cost.

Certain feeders on the South West England section of the Grid are to be equipped with protective gear based on the negative phase sequence principle. The general method whereby this type of current is detected is a novel one covered by a G.E.C. patent, employing the balanced disc type of relay. The presence of either negative or zero phase sequence current unbalances the phase currents, and this unbalance is detected by means of the relay, each element of which is employed for comparing the current in pairs of phases. In the case of the South West England grid, this scheme is modified to prevent operation for zero phase sequence currents.

The scheme is a biassed one, and it has therefore been possible to obtain complete stability, together with a high degree of sensitivity, the relays functioning for faults of 10 per cent at no-load, falling to about 4 per cent at half load, thereupon increasing to about 20 per cent at full load, and ascending rapidly for higher values. The relay unit consists of two shaded pole electro-magnetic elements acting upon a thick aluminium disc of hour glass shape moving about a horizontal spindle, the position of which relative to the magnets can be adjusted, thus giving a variable degree of bias.

An important step has been accomplished in connection with the protection of any type of apparatus for which the beam relay is normally employed, resulting in the halving of the fault settings which were formerly possible. Such an increase in sensitivity is frequently needed for the protection of transformers by means of bar type current transformers with a relatively small primary current. Under these conditions a sufficient VA capacity is usually only obtainable by employing large section current transformer cores. The new type of relay is of the clapper pattern, and differs from the usual plunger type in two respects. In the first place, the relay is inverted so that the plungers are underneath the coil, and secondly the plungers are fixed relatively to the moving portion, which now constitutes an armature with a much more complete iron circuit than previously. The results given by the relays have borne out expectations, and they are being installed in the South West England section of the Grid.

A number of interesting schemes for the protection of transformers have been designed and installed. In most cases bar type transformers have to be employed providing only a low VA capacity, and requiring different core sections at the primary and secondary ends in order to produce a satisfactory balance. Also, change of ratio by tap changing to an extent of as much as plus or minus 17 per cent has had to be covered without any change in the protective scheme. Finally, some of the transformers have consisted of star/star primary and secondary windings with delta-connected tertiaries. All these conditions have been covered by means of standard protective apparatus, which has afforded complete stability and adequate sensitivity.

A novel method of connection has been adopted for a number of the transformers for the British Grid, in which the current transformers are located within the delta of the main transformers. By this means it has been possible to avoid unbalance due to earth currents and a number of other minor causes, which can give trouble in a multiple earthed system.

A considerable amount of work has been done upon earth leakage protection for Grid transformers, not only for Central England, but also for North West, South East, and South West England, leading to very sensitive results, together with the required degree of stability. In Central England, discriminating earth leakage protection has been fitted in connection with current transformers having ratios varying from 300/0.5 to 80/0.5. In the majority of these installations, including those with the smallest ratios, a sensitivity of 20 per cent has been secured.

A scheme has been evolved in conjunction with Pirelli-General Cable Works (one of the associated works of the G.E.C.) for protecting oil filled cables against leakage of oil. The scheme is operated by means of oil pressure switches, which function as soon as the oil pressure decreases sufficiently at any part of the cable, bringing about the isolation of the cable before any damage to the conductor or insulation can take place.

A useful type of lightning arrester, especially suitable for protecting low voltage distribution lines, has been designed upon the carborundum principle, the arc which follows the discharge being split up into a very large number of paths in the interior of a carborundum disc. It is thus easily extinguished. The models of this device available are for line voltages up to 600 volts, and are suitable for A.C. or D.C.; but the principle is being extended to cover higher potentials.

For dealing with internal over-pressures, a surge absorber has been introduced initially for safeguarding mercury rectifiers while they are starting up from cold. For this purpose a device is needed to conduct when an over-pressure exceeding 2 kV occurs, and it should be capable of withstanding continued discharges of this nature for, say, 15 minutes. The surge absorber is based on the non-arcing gap principle with a high capacity low resistance unit in series, which affords a path of the maximum permissible conductivity to the surge, combined with an entirely effective suppression of the over-voltages to be encountered.

Complete equipment for split conductor protective gear is now available, including relays and protective transformers. The transformers themselves have been designed with the minimum depth, so that they can be accommodated in standard 6,600 volt trucks without altering the overall dimensions.

AUTOMATIC CONTROL.

A number of automatic control equipments have recently been installed for operating traction mercury arc rectifiers. This subject will be dealt with at length in a special article which will appear in an early issue of the *G.E.C. Journal*.

In connection with rural distribution, a need has existed hitherto for an oil circuit breaker to protect sections of distribution or transmission line, capable of reclosing the circuit a specified number of times at stipulated intervals. It has been usual to obtain these characteristics by means of rather elaborate lime lags; but a model has now been produced which employs the rotation of the motor operating the oil switch in order to provide graded time lags in between the various operations. By this means the apparatus is rendered extremely simple, and there is nothing which is likely to get out of order. Upon the occurrence of tripping, the oil switch is reclosed after 15 to 30 seconds (according to setting), and if the breaker again trips, the operation is repeated. If the fault persists, the breaker recloses a number of times (according to setting), and is finally locked out until the mechanism is reset by hand.

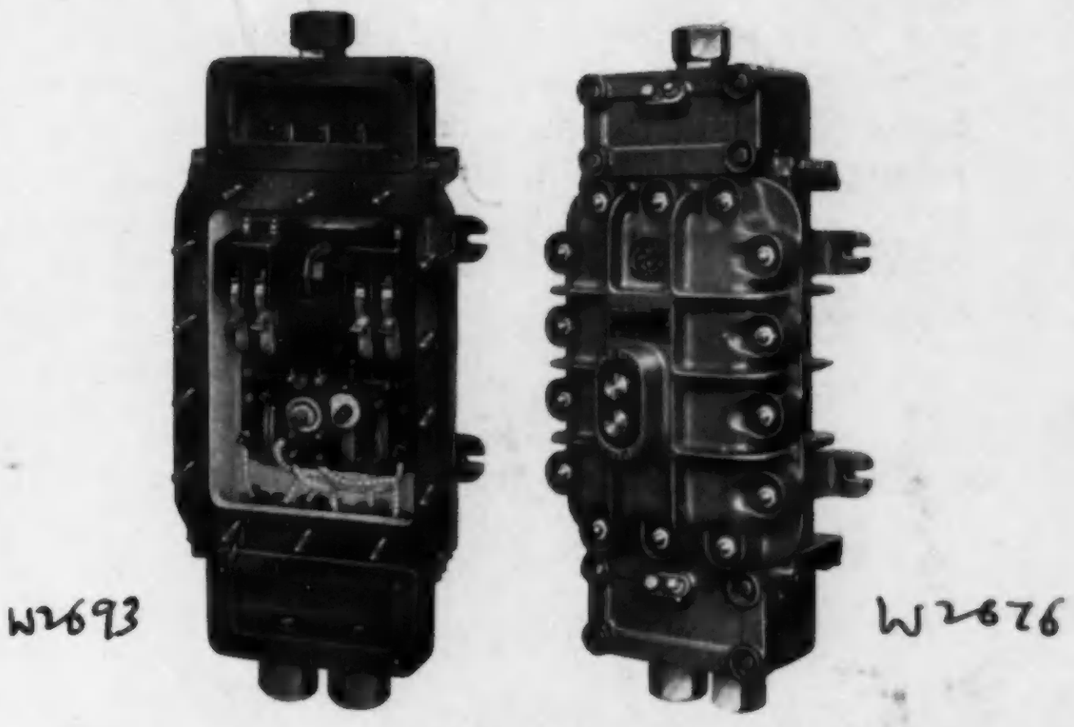

Fig. 17.—Internal and exterior views of flameproof direct-to-line starter.

The practice of automatically synchronising the units of a power station is being looked upon with increasing favour. An auto synchroniser which presents many points of interest has now been produced. It operates directly on the principle of combining the functions of the shift engineer with those of the synchroscope, embodying a motor copying the operation of the synchroscope on a larger scale. When switched into circuit, it directly controls the governor of the incoming set in accordance with its speed relative to that of synchronism, and causes the main switch to be finally closed at the correct position, having regard to the various time lags concerned.

In this connection an interesting problem recently had to be solved in order to overcome an unpleasant vibration which occurred in a large steam yacht, when the twin propeller shafts were rotating at full speed. The problem consisted of forcing these shafts to run with their moving parts in corresponding positions on either side of the ship, that is in exact right and left-handed synchronism. Alternators were to be located on the two shafts, which would be used to supply electric power up to their full load for general purposes. It was found possible to devise a method of synchronising these which could be put into effect by the engineer, who had only to close a switch, leaving the relays to do the rest. The whole scheme was simple and mistakeproof, and should be of service in other situations, such as Diesel engined power stations, where problems of vibration are encountered.

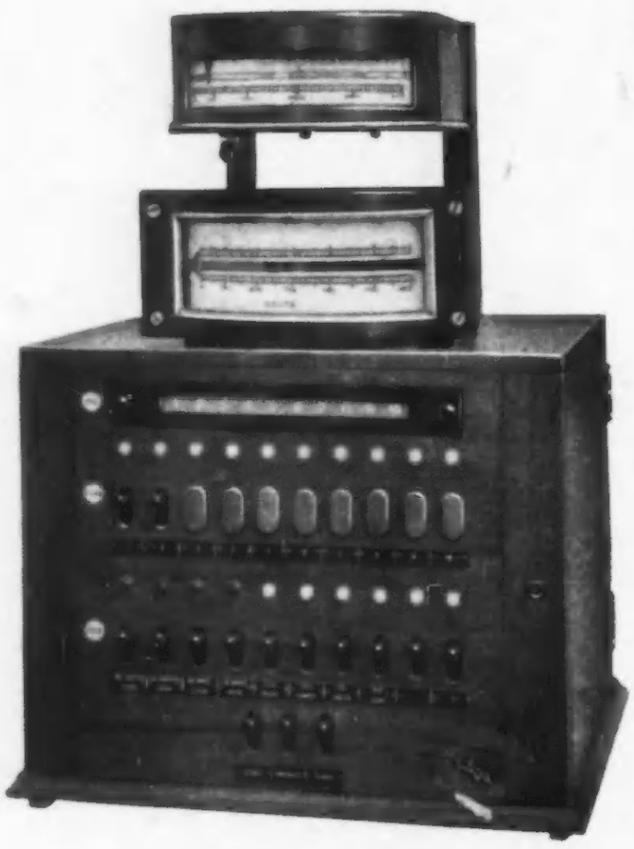

Fig. 18.—Supervisory control unit for the control of two mercury arc rectifiers and B.O.T. earthing panel.

SUPERVISORY CONTROL GEAR.

For some years the G.E.C. has been extending its range of remote supervisory control gear and three main types of equipment have been developed. These are :

(1). The "Ten Point Tandem" system using 4 pilot wires which may be looped into a number of stations so that one set of control equipment can be used to operate equipment in a number of different stations.

(2). The "Twenty-four Point" system using 2 pilot wires per sub-station controlled.

(3). A larger and more flexible type of equipment, also using 2 pilot wires per sub-station, which has an almost unlimited capacity.

The choice of equipment for any particular service depends upon a number of factors, notably the distance between the control point and controlled station and the number of operations to be performed at the remote point. Generally speaking the first two types mentioned satisfy most requirements for remote control, the third type being specially designed for large systems such as those required for the control and supervision of the various areas operated by the Central Electricity Board.

Some of the applications of this type of control gear may be briefly mentioned.

In converting sub-stations remote supervisory control equipment can effect very considerable savings and since a number of stations can be controlled from one central point the most efficient control can be obtained. Any operations which would normally be carried out by a sub-station attendant can be performed at the control point.

The operations usually required are :—

1. Closing and opening E.H.T. feeders.
2. Stopping and starting any type of converter, such as mercury arc rectifier, rotary converter, motor converter, or motor generator.
3. Meter readings of the load or voltage on any part of the system.
4. Closing and opening D.C. feeders.

(*b*) *Railway or Tramway Sub-stations.*

Supervisory remote control is particularly well suited for controlling a railway system and as the stations to be controlled will necessarily lie along the track, the tandem is particularly useful. Thus the one set of four pilot wires will loop into each station. In addition to the switching operations mentioned above, it will probably be necessary to control track sectioning circuit breakers installed in huts between the sub-stations. Here again the pilot wires will be looped into the circuit breaker huts.

(*c*) *A.C. Distribution Systems.*

In most A.C. distribution systems there are a large number of switching and transformer stations, either of the outdoor or kiosk type. It is a great advantage, particularly during line faults, to be able to re-arrange the network quickly from a central control point. Supervisory equipment enables this to be accomplished speedily and efficiently and also enables meter readings to be obtained of the loads on various sections of the system.

A further very important field in this class of work is the operation of on load tapping switches on transformers from a control point so that the voltage of the L.T. network can be regulated at any time to suit the load on the system, readings of the L.T. voltage at various points on the system also being readily obtained.

Again, if the voltage on the system is controlled by induction regulators or neutral point regulators these may also be operated from the central control point.

(*d*) A further important application is the

remote control of storm water or emergency pumps, the operation of release valves, sluice gates, etc. In this connection remote indications of water levels can be obtained or an alarm sounded when dangerous variations of water levels occur.

The application of supervisory gear to the grid is referred to on page 34.

FLAMEPROOF SWITCHGEAR.

A considerable amount of development has taken place in connection with all types of flameproof apparatus for use in mines. The policy of making the enclosure sufficiently strong to resist the full explosion pressure without introducing special vents has been extended to much larger equipment than heretofore. A direct gain in simplicity accrues from this construction, and the latest mining requirements are fully complied with.

An improved 10 h.p. 440 volt flameproof direct to line contactor starter is illustrated in fig. 17; the strength of the case is apparent. Push button control is provided for starting and stopping. Time limit relays of the hand resetting type are fitted, resetting being effected by pressing the "stop" push button.

For use with liquid controllers required for haulage motors of the order of 25 h.p. a flameproof air break reversing contactor, and a flameproof master switch have been designed. The handle of

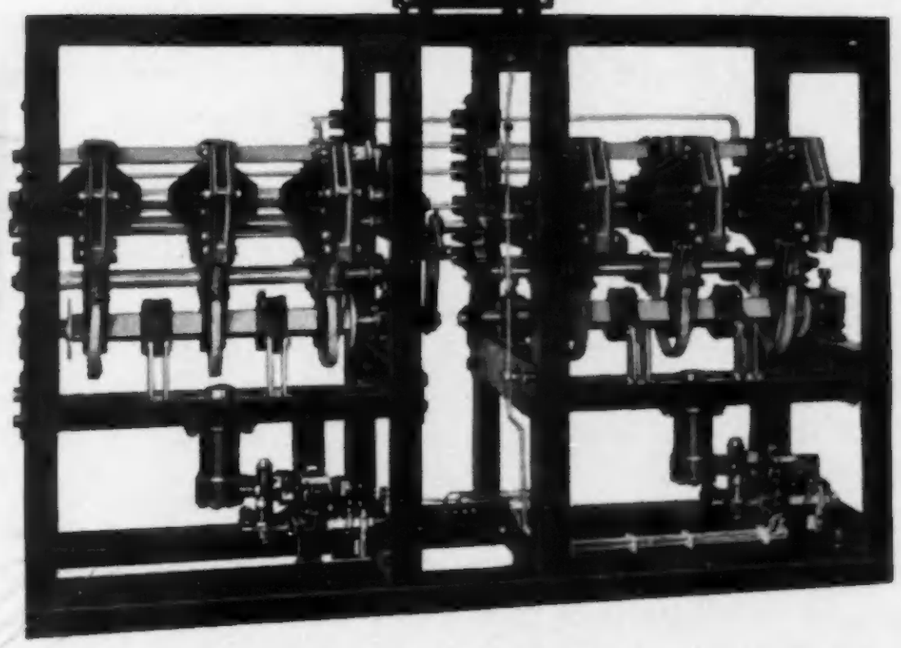

Fig. 19.—Pneumatically operated air-break reversing contactor for 1,000 h.p. A.C. winder.

the master switch operates the stator reverser, and raises or lowers the electrodes into the electrolyte. The reverser is equipped with two four pole contactors, the forward and reverse contactors being mechanically interlocked, so that it is impossible for them both to close at the same time. Overload protection is provided in all three phases, the relays being of the hand resetting type with inverse time features, protecting the motor against short circuits.

STARTER AND CONTROLLER GEAR.

The standard range of automatic direct to line starters has been made of a very representative nature, sizes being available for motors ranging from ½ h.p. to 30 h.p., at voltages up to 550. Both reversing and non-reversing patterns are included in the range.

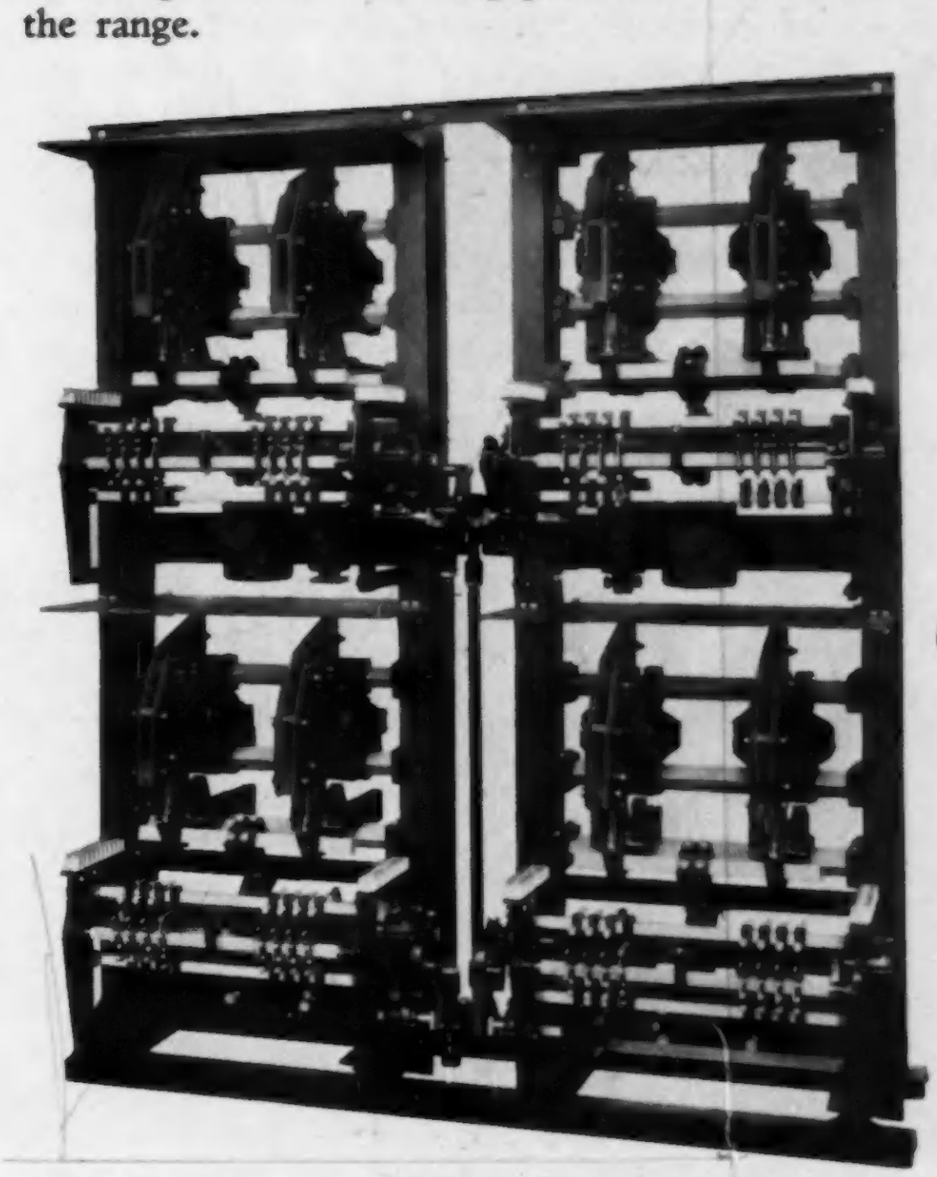

Fig. 20.—Heavy current contactor, based on line contact principle, capable of dealing with currents up to 2,000 amps at 5,000 volts.

Thermal tripping is now applied to this type of motor up to 15 h.p., the tripping on overload being carried out by means of thermal strips of large section. They are so designed that a single calibration is sufficient to set the tripping current for all three phases, continuous adjustment being given for all overloads ranging from 25 per cent to 100 per cent. One of the difficulties encountered with this type of trip gear is that the thermal element may be damaged by a heavy short circuit current before the starter has time to trip. The difficulty, however, has been overcome by embodying bi-metallic strips of many times the usual sectional area, which are immune from this risk. A larger pattern is being developed for controlling a further range of motors of 20 h.p. and upwards.

Investigation of blow-outs and contacts has rendered possible an increase of about 30 per cent in the current capacity of contactors.

An example of recent practice in small contactor design is a switchboard indicating contactor which consists of an enclosed double-pole D.C. contactor of 5-amp. capacity. It is fitted with a latch holding

it closed after the coil has been de-energised, and an indicator to show when it has been tripped. Its principal purpose is to close separate circuits for the indicating lamps and alarm bells which signal the position of a circuit breaker.

A pneumatically operated air-break reversing contactor for heavy duty, *e.g.*, as used for electric winders, is shown in fig. 19. The fixed contacts and arc chutes are mounted on a channel iron framework, the moving contacts (of which there are two sets of three) being mounted on two square insulated shafts carried in bearings fixed to the main framework. Mechanical and electrical interlocks prevent the forward and reverse contacts being closed at the same time. An auxiliary contactor and transformer prevent one set from closing so long as there is any voltage across the other. This is necessary in order to ensure that the arc is completely cleared before connections are made for reversing the motor.

The moving contacts are operated by means of compressed air, which is controlled by electro-pneumatic valves. The air cylinders are situated below the moving contact shaft, and are designed to operate with air at 70 lbs. per square inch pressure, although this pressure may be varied to suit special requirements. The contacts close with a rolling action, and arcing contacts are provided to relieve the main contacts from breaking the full current. Arc chutes are also fitted with blow out coils.

Heavy current contactors have always presented somewhat difficult problems to designers, and as it was felt that the conventional design of contactor was reaching its limit of useful application, so far as heavy current was concerned, attention has been directed towards the principles embodied in the G.E.C. line contact circuit breaker. As a result an extremely robust latched type of contactor (fig. 20) has been designed. By using shunted instead of series blowout coils the use of flexible braids was reduced to a minimum, and a contactor capable of dealing with normal currents up to 2,000 amperes A.C. at 5,000 volts has thereby been made possible. This type of switch was designed originally for marine service, but it has wide application also for land work. Another class of starter apparatus, originally designed for marine work, is being used for industrial purposes. This is the plural starter system, described in the *G.E.C. Journal*, Vol. III, No. 1, Q.T.E.V. "Monarch of Bermuda."

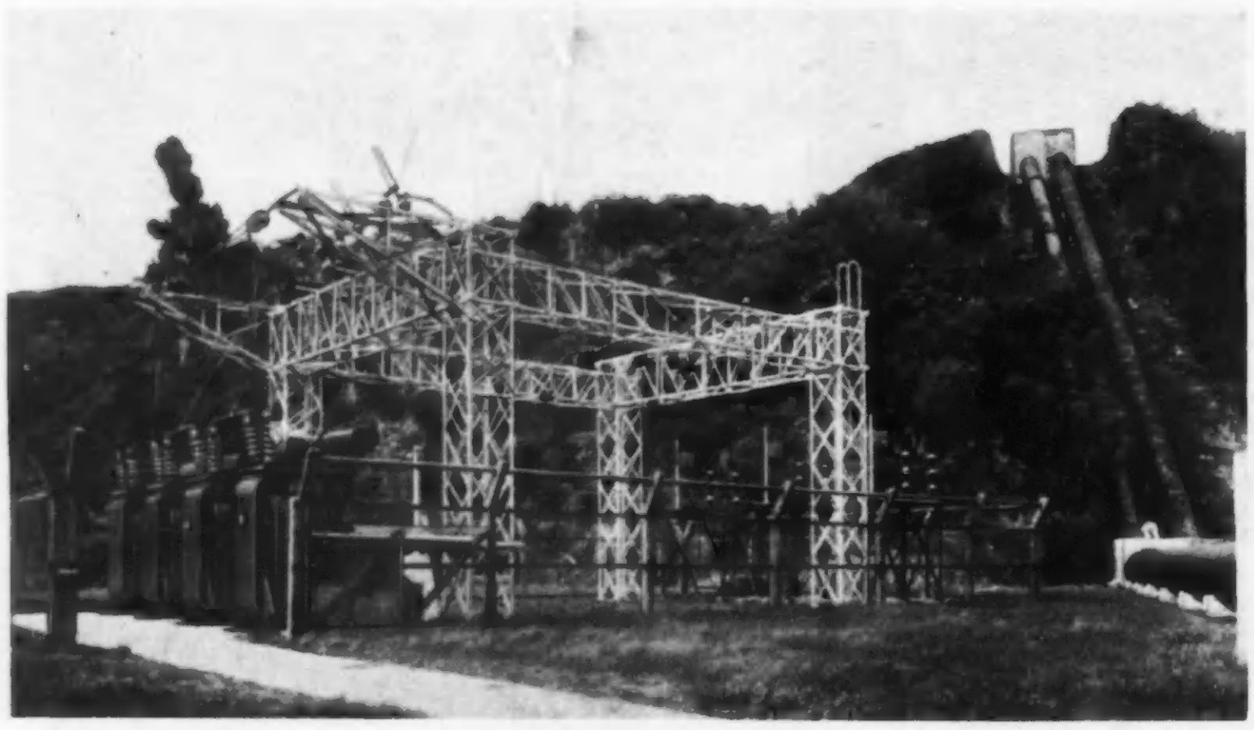

Fig. 21.—Typical outdoor transformer and switching station in New Zealand.

OUTDOOR SWITCHGEAR.

A large quantity of outdoor switchgear has been manufactured and erected for the main 132 kV Grid scheme in South West England, while further apparatus is being made for 33 kV Grid lines in other parts of the country. For the C.E.B. Northern Ireland, special kiosks have been designed for use in connection with overhead transmission and rural distribution schemes. On some of the smaller sites kiosks suitable for mounting at the base of the transmission pole are being installed. They are erected about two feet from the ground; the cost of foundations is thereby saved.

Other outdoor schemes for which overhead equipment is being manufactured include those for Egypt and Tangier.

A type of street feeder pillar of welded sheet steel construction has completely supplanted the earlier cast iron patterns.

TRANSFORMERS.

Development work in connection with transformers has lately been focussed principally upon special types. Reference was made earlier in this article to the completion of fifteen mercury arc rectifiers for traction service. Considerable importance attaches to the design of rectifier transformers from the point of view of regulation of the rectifier. This matter will be discussed in some detail in an article which will appear in the next issue of this Journal.

Several large transformers for use with electric furnaces have been manufactured. Owing to the large secondary current involved, special methods have been devised for the insulation of the low voltage windings.

Two 6,250 kVA 66 kV transformers exported to Spain possess somewhat unusual cooling features, in that the cooling equipment comprises a circulating pump driving the hot oil from the transformer through a cooling radiator immersed in the tail race of a hydro-electric plant.

A special design of radiator was needed owing to the water containing finely suspended vegetable life which builds up into a fungoid growth on any clean surface. This difficulty was surmounted by the use of a radiator having plain tubes without gills, the spacing of the tubes being sufficient to enable cleaning operations to be carried out by means of a wire brush without removing the radiator from the tail race. Circulation of the oil, while the transformer is in service, is assured by a centrifugal pump, which delivers the necessary volume against the resistance head.

As it is of vital importance that no water should leak into the oil, the cooler was subjected to the most stringent tests before installation, and had to withstand a water pressure of 150 lbs. per square inch for two hours. It should be mentioned, however, that even should there be a fissure in one of the tubes the pressure of the oil in the radiator would effectively prevent the ingress of water through the fissure.

The practice of employing separate radiators for large transformers is increasing, and a typical unit designed upon this principle is illustrated at fig. 22.

Improvements in detail are continually being made in the design of tap changing gear. An addition

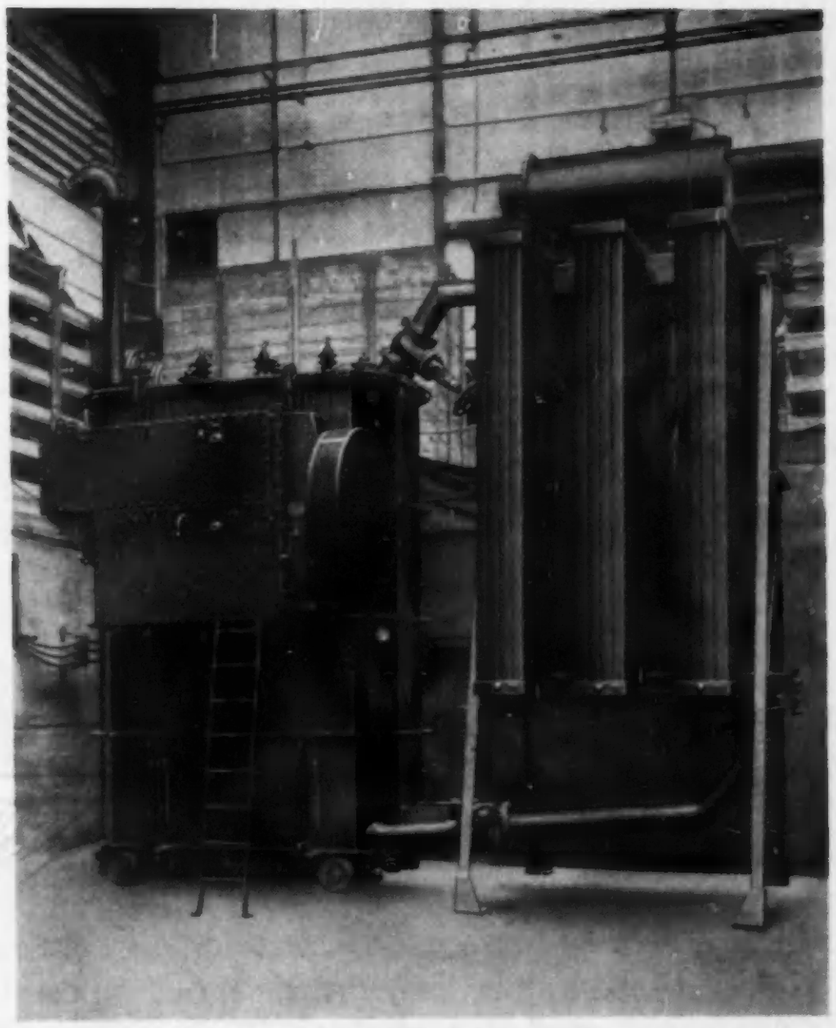

Fig. 22.—7,500 kVA, 30,500/10,750 volt transformer for Northampton, equipped with on-circuit tapping switch; self cooled, with separate radiator.

to the range of off-load tap changing gear takes the form of a rotating tubular type of switch (known as type "Z"), with contacts mounted in varnished paper tubes. The line contact principle is employed. The switch is capable of dealing with pressures up to 33 kV and currents up to 100 amperes. The standard switch provides five voltage variations, and thus complies with the great majority of specifications, which call for a variation of plus or minus 2.5 and 5 per cent.

The design of oil immersed reactors is closely linked with transformer practice. During the year the demand for this class of reactor has been

Fig. 23.—Iron shrouded, oil immersed reactor, 200 amps, 6,600 volts, 3 phase, 50 cycles.

increasing. In large measure this is accounted for by the extension of the grid, resulting in the need for limiting possible short circuit currents to a definite value, in order to safeguard existing switchgear. The oil immersed reactor shown at fig. 23 represents typical practice, and is one of thirteen manufactured for one section of a power system. The design is of an iron shrouded oil immersed type with self cooling.

MARINE ELECTRIFICATION.

The Q.T.E.V. "Monarch of Bermuda," already referred to in this article, has proved more than capable of the work for which she was intended. Her performance in service was given in detail in *G.E.C. Journal* (Vol. III, No. 3, page 141). The fact that a repeat contract of a most unusually comprehensive nature was placed with the G.E.C. for the electrical equipment of the sister ship, the Q.T.E.V. "Queen of Bermuda," affords perhaps the best proof of the satisfaction given.

It is somewhat natural, in view of the success achieved by the "Monarch of Bermuda," that the equipment for the sister ship should be as nearly as possible identical. But certain new features representing the very latest practice have been incorporated. As an example, it was decided to substitute for the oil ring and pump method of lubrication of the propulsion motors, a disc form of lubrication, as being more suited for a machine operating over a very wide range of speeds, and in particular running for long periods at very slow speeds. This disc method of lubrication makes use of a large disc

fitted to the outboard end of the shaft just inside the bearing housing. The disc revolves in the oil, which is brought up to the top of the disc at every revolution. The oil is taken off the disc at the top by means of a metal scraper, and is fed into a trough. It next passes on to the top of the shaft at the centre of the bearing, from which it is distributed along the whole length of the bearing surface, returning by gravity to the oil well.

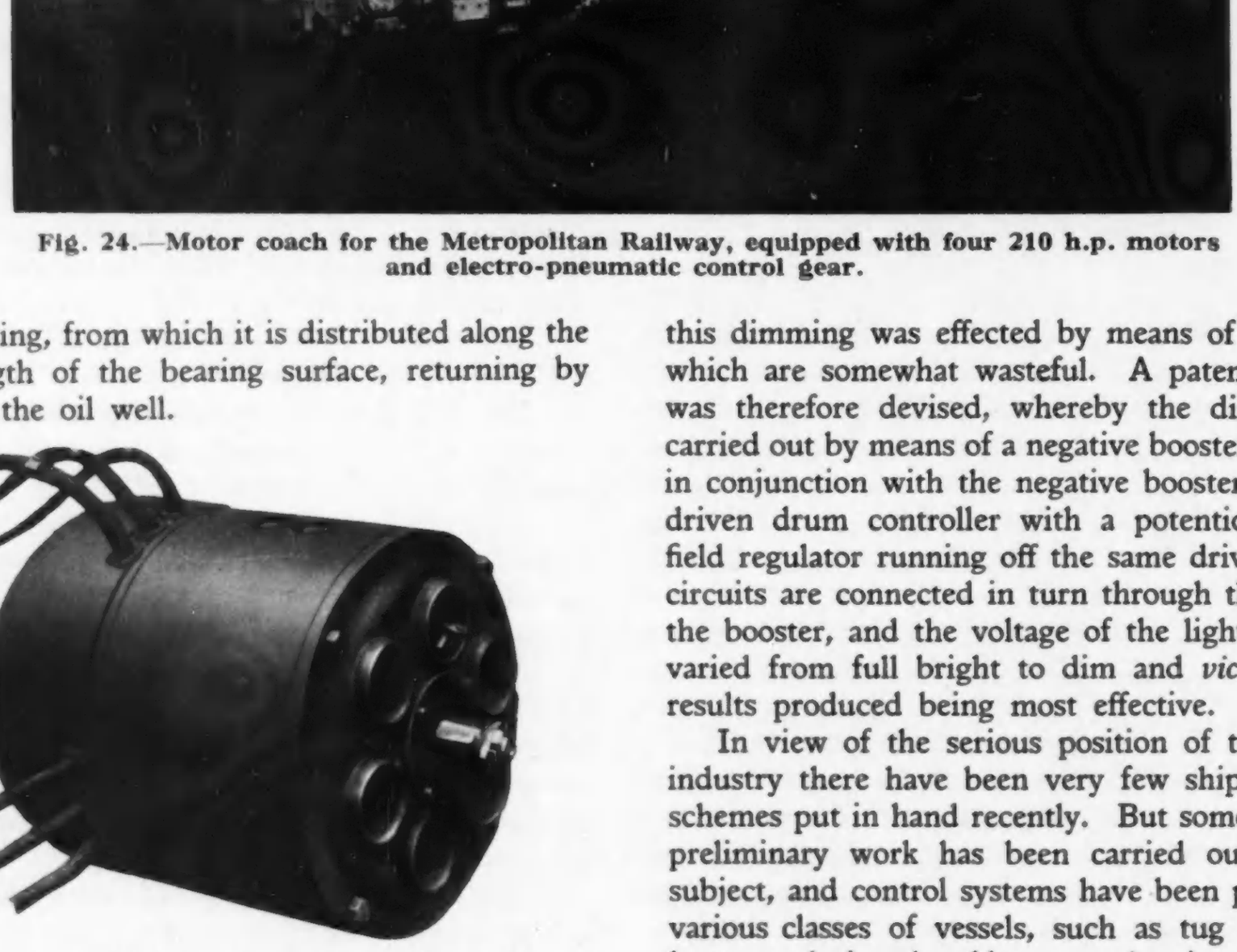

Fig. 24.—Motor coach for the Metropolitan Railway, equipped with four 210 h.p. motors and electro-pneumatic control gear.

Fig. 25.—Battery vehicle traction motor ; 60 amp 40 volt rating.

Improvements have also been made which render the manipulation of the controls and emergency controls even simpler than before. A front view of the main control board forms the frontispiece to this article.

Another interesting development on this vessel is in connection with the lighting of the dancing space, a separate coloured lighting being provided for each of three sections of this space. The lights are dimmed and brightened in sequence to give a multi-colour effect. On the "Monarch of Bermuda" this dimming was effected by means of resistances, which are somewhat wasteful. A patented scheme was therefore devised, whereby the dimming was carried out by means of a negative booster. Working in conjunction with the negative booster is a motor driven drum controller with a potentiometer type field regulator running off the same drive. Various circuits are connected in turn through this drum to the booster, and the voltage of the lighting circuits varied from full bright to dim and *vice versa*, the results produced being most effective.

In view of the serious position of the shipping industry there have been very few ship propulsion schemes put in hand recently. But some interesting preliminary work has been carried out upon the subject, and control systems have been prepared for various classes of vessels, such as tug boats, ferry boats and ice breaking vessels, in addition to passenger ships. Diesel-electric equipment for a large tug which is to be electrically propelled is in course of manufacture.

Mention should be made in particular of schemes for adding additional power to existing vessels by the insertion of a D.C. electric motor in the main

propulsion shaft of either a Diesel driven vessel or of a reciprocating steam engine vessel, and patents have been taken out covering the electrical equipment of such schemes.

In the case of Diesel driven vessels, an auxiliary constant speed Diesel engine is installed for driving a Ward-Leonard generator to operate the motor in the propeller shaft line, and patented load sharing devices have been designed to ensure that the electrical equipment shares the load proportionately with the main Diesel equipment, quite independently of any action by the engineer-in-charge.

This scheme also enables the main engine to be started up or reversed by the electrical system without the use of compressed air; it also results in considerable economy in the upkeep of the main Diesels.

For reciprocating steam plants an additional motor is inserted as before, but in this case the machine is supplied by a generator driven by an exhaust steam turbine, obtaining its steam from the exhaust from the low pressure cylinder of the reciprocating engine. In this case the electrical gear is arranged to start, stop and reverse simultaneously with the main steam engine, and automatic load sharing combinations are also in use as with the Diesel equipments.

Of the utmost value to marine work from the national standpoint is the new ship testing tank in the William Froude Laboratory at the National Physical Laboratory. The tank was opened by the Rt. Hon. Stanley Baldwin, M.P., on November 18th last. The electrical equipment associated with the tank (which is of G.E.C. manufacture), is called upon to perform extremely delicate operations. A wax model of the ship to be tested is attached to a towing carriage driven by two 30 h.p. direct current motors supplied from a Ward-Leonard motor generator set. In order to ensure the highest possible degree of accuracy in testing, the speed of the carriage must not vary more than .25 per cent during a test.

In addition a small electric motor is mounted in the actual wax model of the ship to drive the propeller. When tests of this character are being made the model is not towed, but propels itself. The towing carriage follows the model, and is connected by flexible cables to a small propulsion motor in the model so that all necessary data can be acquired. The propulsion motor is supplied with power from a small motor generator mounted on the carriage.

ELECTRIC TRACTION.

A large number of equipments for motor coaches have been in progress. Those for the Metropolitan Railway (fig. 24), embodying electro-pneumatic control, were briefly described in the *G.E.C. Journal*, Vol. III, No. 1, page 14. A contract for the Euston-Watford section of the L.M.S. includes equipment (in accordance with the Oerlikon system) for eight motor coaches, thirteen driving trailers and ten trailer coaches. The equipments are somewhat heavier than those for the Metropolitan Railway, each motor coach, fig. 24, being provided with four 280 h.p. one hour rated motors, as compared with four 210 h.p. motors. The control equipment, which is of the electro-magnetic type, is divided into two independent groups, and is arranged for series-parallel

Fig. 26.—Witton-Kramer magnetic rail handling equipment.

control. A point of interest is that the layout has been especially designed so that all control equipment is carried on two frames capable of easy removal from the coach. The two frames are arranged for rolling out of the side of the coach after the connections have been broken and the fixings freed. The object is to facilitate the cost of general overhaul which takes place at regular periods of a few years. The fixings of the frames to the coach have been made exceptionally strong and secure, but at the same time they may be easily uncoupled.

In order to obtain increased speed, the motors have been arranged for two weak field positions—actually taps to the main field. The equipments, nevertheless, are capable of running in multiple with earlier equipments supplied, apart from the weakest field connection.

Trolley Bus equipments are in course of construction, in particular for the Llanelly and District Electric Supply Co., Ltd. They are for four wheeler double deck buses. The driving unit is an 80 h.p. series motor, built for mounting under the bus body and consequently of a special flat design. The layout of the equipment is thereby simplified, and the length of the transmission is reduced. The motor is of the super saturated type, *i.e.*, it is capable of a wide range of economic regulation by means of a field diverter. This gives the advantage that a greater number of running steps are available, and by reducing the time taken to cut out the series resistance in starting, the energy loss in the resistances is very much reduced.

A range of compressor and exhauster motors for trolley buses has been introduced. The exhauster motor is rated at 0.95 h.p. at 500/550 volts, and is direct coupled to the exhauster. The motor is operated by a direct to line starter. The compressor

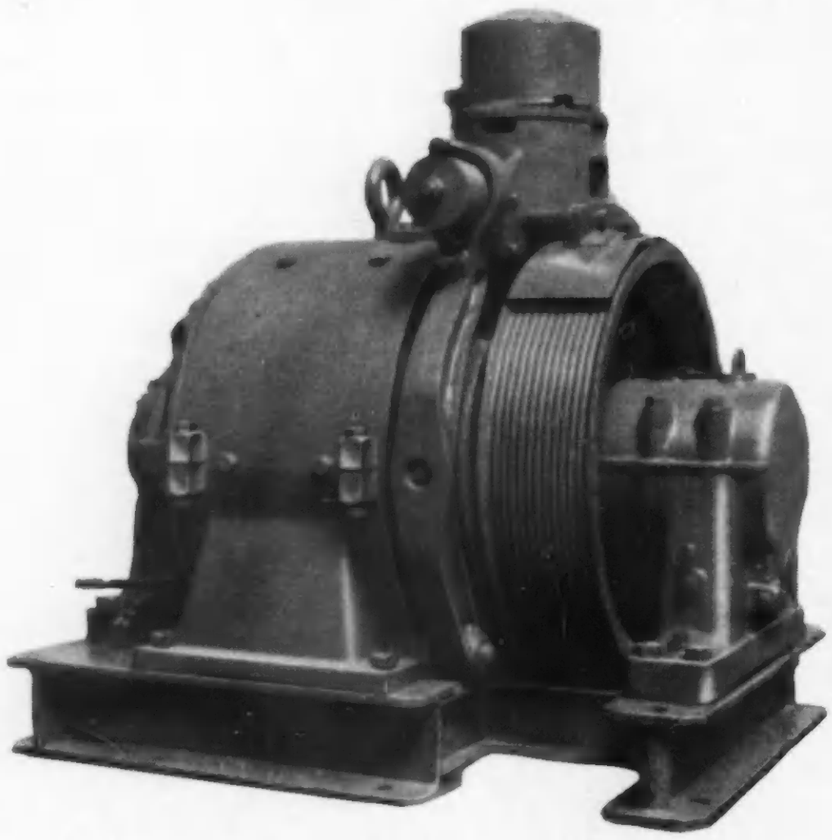

Fig. 27.—Slow speed D.C. motor for lift service.

motor is built as an integral part of the compressor, and is rated at 0.75 h.p. at 500/550 volts. It has to be capable of switching direct to the line. The frame of the motor is fabricated and the armature is built on a hub which is pressed on to an extension of the crank shaft.

Another small motor for traction purposes is the W.T. 5V, fig. 25, which has been produced for battery vehicle service. It is a ventilated machine, rated at 60 amp 40 volts on a one hour rating. This motor is designed to withstand the heavy overloads associated with battery vehicle service. It is also capable of the high overspeeds due to overrunning down inclines. The frame is of fabricated construction.

ELECTRIC HOISTING EQUIPMENT.

Lifting magnets as made in the Witton-Kramer Tool and Hoist Works at Witton are continually being applied to novel and interesting purposes. An example of rail handling by means of bipolar magnets is illustrated in fig. 26. The equipment consists of three 25in. by 18in. bipolar magnets fitted with aluminium coils and carried on a suspension beam.

The magnets have to lift six rails of 1.1 per cent manganese content, each 60 ft. long and weighing one ton. This is easily achieved with a factor of safety of about 100 per cent by using the centre magnet; without the centre magnet the safety factor would be reduced practically to zero.

Provision is made for easy adjustment of the magnet centres to suit the varying lengths of rails, by means of a small hand winch mounted at one end of the beam, the magnets being carried on small trolleys which run along the beam, while locking bars are provided to fix the magnets in position at the required distance apart. The magnets are suspended from the crane by means of two hooks which give a very steady lift and prevent the rails from swinging. Provision is also made for lifting rails on an angle up to 25° from the horizontal by means of an additional single hook suspension

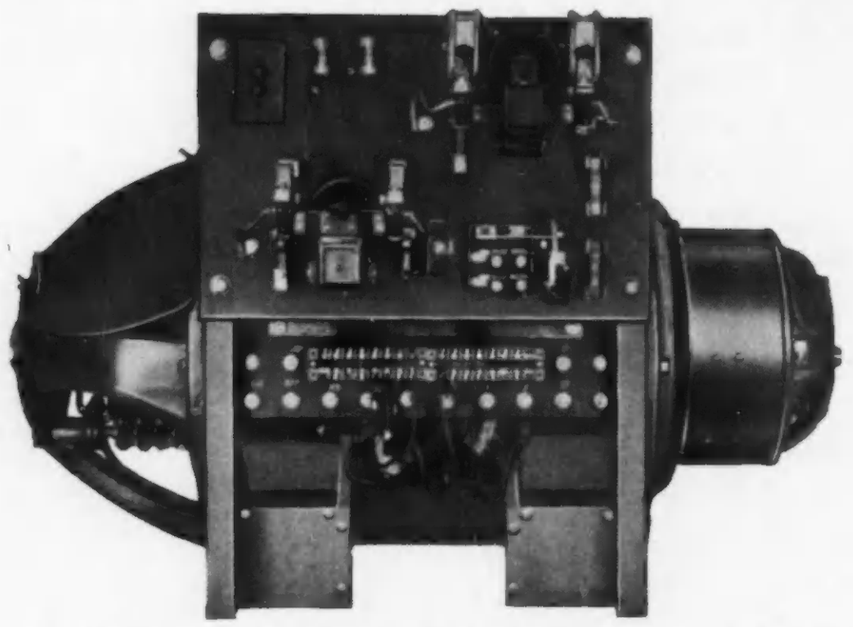

Fig. 28.—Generator for use with lift motors installed on an A.C. supply.

which can be used instead of the two point system of suspension.

The cable arrangement is carried in wooden clamps with a terminal box in the centre of the beam to connect up the main cable from the cable drum. On the crane crab a double sheave spring cable drum is used to reel and unreel the cable carrying the supply to the magnets. In order to

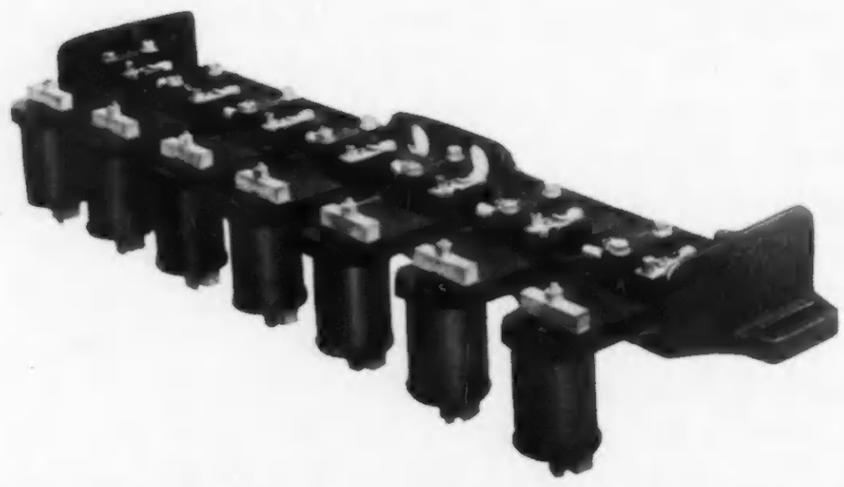

Fig. 29.—Inducer boxes employed to obtain automatic accurate decking.

enable the beam to be removed easily from the crane hook, cable couplings are provided.

The control gear for the magnets consists of an automatic contactor panel operated by a small master control switch.

ELECTRIC LIFTS.

The recent demand for high lift speeds and more discriminating control systems has led to many new developments by The Express Lift Co. (an associated company of the G.E.C.).

The use of high lift speeds has led to the "gearless" lift machine, a large D.C. slow speed motor on whose armature shaft the sheave for the lift cables is mounted direct without any intermediate gearing. The former practice, in which the hauling sheave was driven by a high speed motor through worm gearing, was limited in application to lift speeds of not over 350 ft. per minute. Using gearless motors, installations are now running satisfactorily at twice this speed. A complete range of such motors has been designed and manufactured, of which a typical example is shown in fig. 27. In this illustration there may also be seen the large diameter electro-magnetic brake used for holding the lift when the motor is de-energised.

Variable voltage control is used with the gearless machines as well as with the higher grade of geared lifts, to give smooth acceleration and retardation. The motor generator sets for this system are very compact and simple in construction. Both armatures are mounted on a common shaft, and both frames are combined into a single rolled steel cylinder. An exciter is always provided when the main supply is alternating current, in order to provide a constant direct current voltage for the control circuits. A typical set, including exciter is shown in fig. 28.

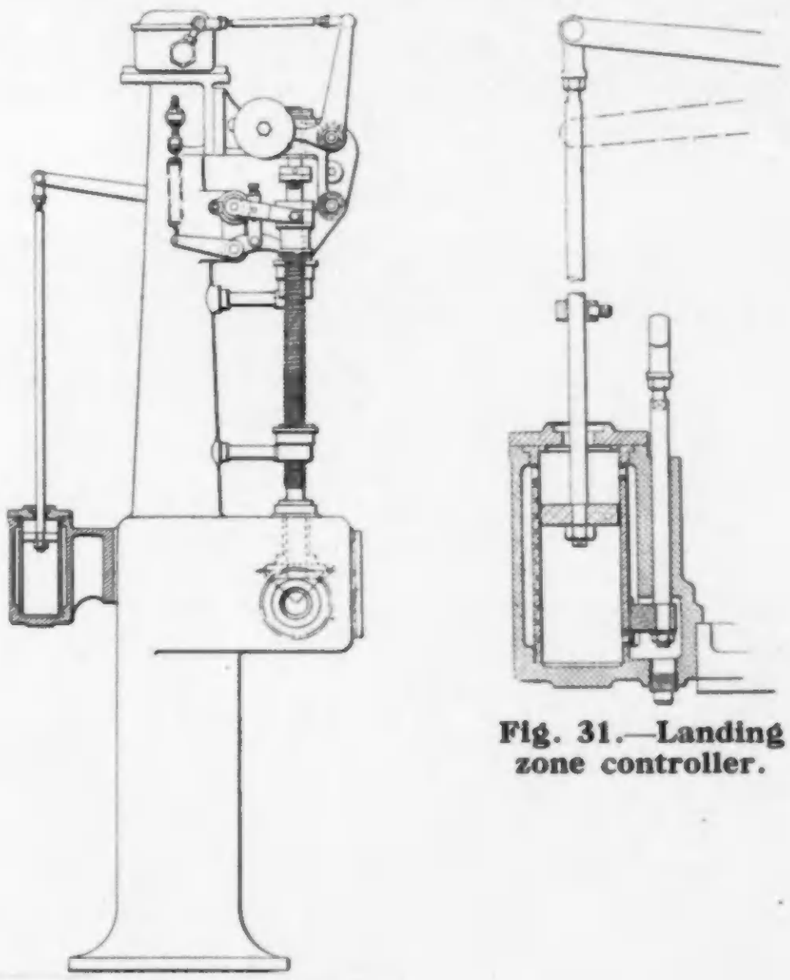

Fig. 30.—Improved type Whitmore overwinder gear

Fig. 31.—Landing zone controller.

Full operating effectiveness can only be obtained from the high speed variable voltage systems when accurate stopping at a floor is ensured without "inching" or slow speed levelling. To attain this end the inducer system has been developed.

It employs an inducer box, as shown in fig. 29, which is mounted on the car and used in conjunction with plain iron inducer plates located in the hatchway. As the inducer box passes the plate during the travel of the lift, the inductive effect of one inducer coil upon its neighbour causes current to flow in the control circuits so operating a relay in the motor room which begins the stopping of the lift. No sound is heard in the lift car, as there is no mechanical connection or circuit opening on the car. A number of such plates are passed, bringing the car through its various stages of deceleration to a final accurate stop at the floor level.

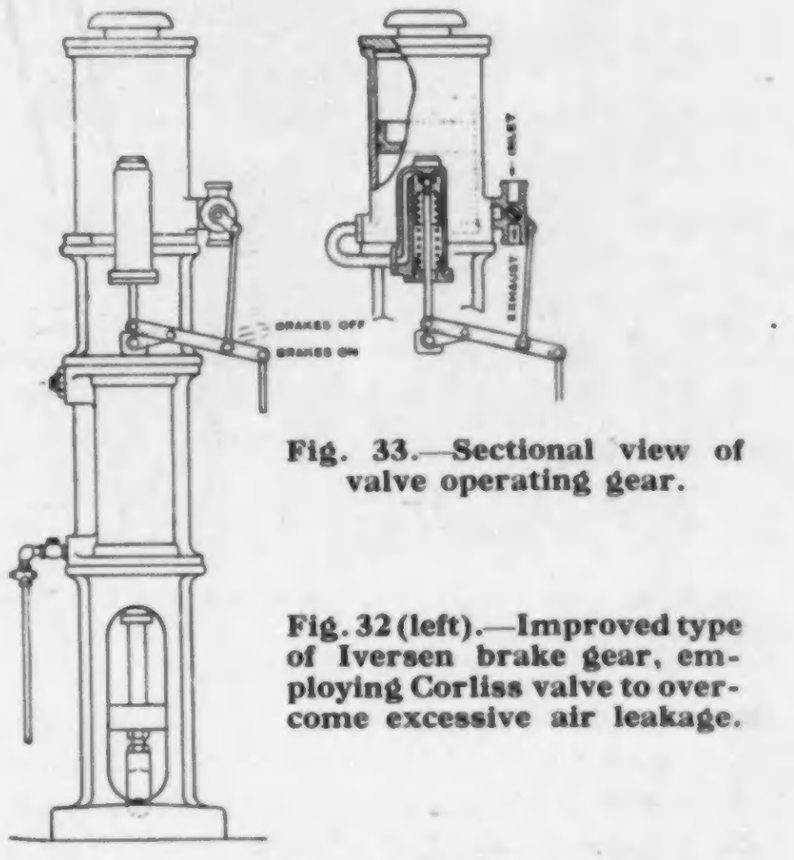

Fig. 33.—Sectional view of valve operating gear.

Fig. 32 (left).—Improved type of Iversen brake gear, employing Corliss valve to overcome excessive air leakage.

Further improvements in lift operating schedules can be made by the use of control systems, which take out of the hands of the attendant the duty of stopping the car to answer calls, and also by means of various signalling systems, which reduce the delay of passengers entering the lift.

With these control and signalling systems, it is necessary to operate several electrical circuits as the car approaches, passes or leaves a particular floor. A device for performing this function is known as the "floor selector." The vertical panel of the selector carries a number of fixed segments spaced to the various floor levels on a reduced scale. Over these fixed segments pass two carriages with moving contacts, the carriages being lifted and lowered by means of a miniature lift gear on the top of the selector. This construction permits of wide multiplication of the circuits operated.

The method of driving the moving contact carriages so that they will be synchronised with the travel of the lift in the well employs Witton "Twyntork" motors (described earlier in this article), one on the small lift gear on the selector and one driven by any convenient means from the car.

STEAM TURBINES.

Reference has already been made in this article to the performance of the Q.T.E.V. "Monarch of Bermuda" and the equipment for the "Queen of

Bermuda." Mention should be made here of the type of governor fitted to the turbines driving the alternators which supply the propulsion motors. It includes an automatic double throttling of steam at the inlet to the turbine which ensures entirely satisfactory control even at the very lowest speeds.

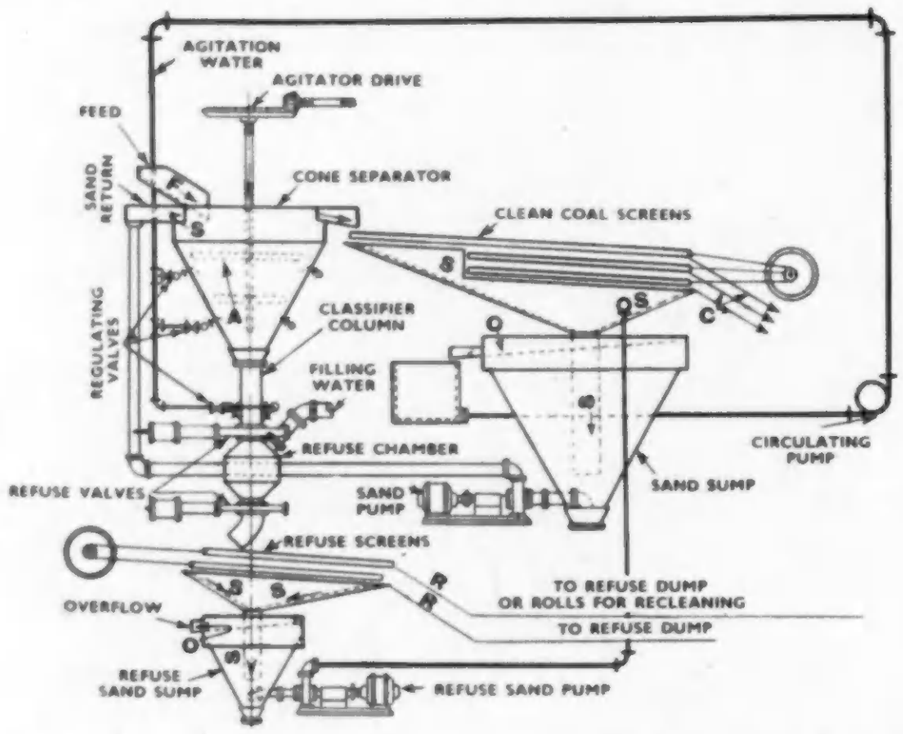

Fig. 34.—Diagrammatic arrangement of "Chance" coal cleaner. A–Agitation Water ; C–Clean Coal ; F–Feed ; R–Refuse ; S–Sand ; O–Overflow.

The required speed setting is obtained by means of a single control, which operates the electrical switching apparatus in proper sequence at the same time.

The development of industrial steam turbines for the combined supply of power and process steam has made further headway. The new Fraser & Chalmers pass-out governing for such turbines has proved efficient and reliable ; its special characteristic is the nozzle-cut-out arrangement, not only at the inlet, but also at the L.P. part of the turbine ; this has very substantially reduced the throttling losses at partial loads thereby increasing the overall economy.

It is well known that a small blade height adversely affects the turbine efficiency. High speed turbines are therefore now constructed having small diameter wheels but longer blades. This development is exemplified by three 3,750 kW turbines at present in construction for running at 6,000 r.p.m., coupled to alternators by means of speed reducing gears.

WINDING ENGINES.

An improved type of "Whitmore" overwinder, fig. 30, now available, affords all possible safety when landing the cage. The device has an additional connection which can be operated when winding men, so as to give an enforced slower winding speed when approaching banking level (fig. 31). The new feature comprises a system of levers connected to a plunger which works in a dashpot, the plunger being released when the cage approaches bank. The rate of fall of the plunger is controlled by a series of ports in the dashpot, which can be varied to suit any given set of conditions. The cycle of this falling plunger represents in miniature the cage approaching bank, and if the speed of the cage should exceed the predetermined cycle a trip is engaged which cuts off the current and applies the brakes.

When winding men, the arrangement of the ports in the dashpot is altered, the bottom opening being rather larger. This opening is closed by a system of connection to the platform, which is operated by the driver when winding men. The rate of fall of the plunger is then slower than that of the normal cycle, which enforces a slower approach of the cage to banking level. The additional protection given by this arrangement when winding men is a valuable feature, and is likely to have a widespread application in the future.

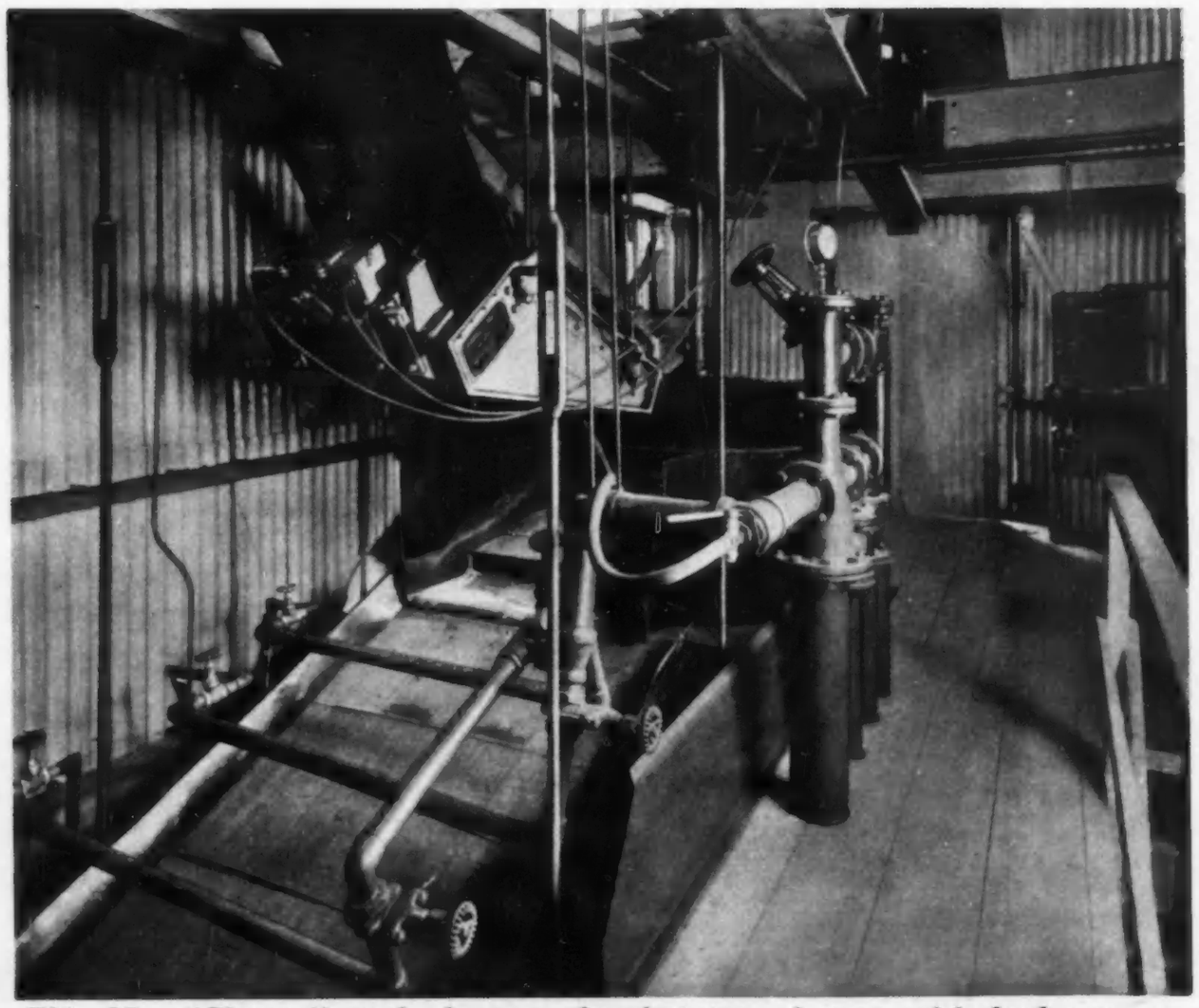

Fig. 35.—"Chance" coal cleaner, showing top of cone with feed screens and clean coal screens.

In recent years the Iversen type of brake control gear has to some extent replaced the old floating valve mechanism. In the Iversen gear a piston valve has usually been employed, which gives rise to trouble, due to excessive air leakage, the air required being three or four times that of the older type of engine.

To overcome this a new type of Iversen gear has been developed, which employs a Corliss valve in place of a piston valve. The Corliss valve, as is well-known, has self-sealing properties and reduces air leakage to a minimum. This new valve gear is shown in figs. 32 and 33, from which it will be seen that all working parts are external and easily accessible. The valve is 1⅛ins. in diameter, which gives very sensitive operation and a minimum of air leakage.

COAL WASHING.

The "Chance" washer offers important advantages in the practice of coal washing from both the technical and economic points of view. Extensive tests have been made upon an experimental plant using a variety of coals, and entirely satisfactory results have been achieved. A plant is now being built for a well known colliery company.

Briefly, the system is a commercial application of the laboratory "sink and float" method, the expensive chemical solution used being replaced by a mixture of sand and water, kept in a fluid state by mechanical and hydraulic agitation. The density of this mixture, which can be varied, is so arranged that the coal floats and impurities sink.

A diagrammatic arrangement of a "Chance" coal cleaner is given in fig. 34, which is capable of dealing with any size of material down to $\frac{1}{32}$ of an inch. Separation of the coal and refuse takes place in the cone due to the different specific gravities. The clean coal, together with some of the fluid mass with which it is mixed, flows out of the cone on to the clean coal screens for de-sanding. Apart from this de-sanding, the screen also sizes the clean coal as required, and it is then delivered either to trucks or storage hoppers.

As separation occurs purely by gravity, cobbles, nuts and smaller sizes of coal can be cleaned in one unit. In this way considerable savings in labour costs can be effected. The elimination of the cost of cobble picking alone often covers the capital cost of the cleaner in a very short time, even though no account be taken of the other numerous advantages of the plant. The plant has a low power consumption, and in spite of the very high washing efficiency obtained, is most competitive in capital cost.

DIESEL ENGINEERING.

Recent figures obtained from power stations equipped with Fraser & Chalmers Diesel engines show that in one, where there are a number of other makes of engine, the consumption during the year 1931, before the Fraser & Chalmers engine was installed, was .65 lbs. per unit generated, and in the year 1932, with the Fraser & Chalmers engine, the consumption dropped down to .59 lbs. per unit. The lubricating oil consumption also showed a considerable improvement, a figure of .0034 lbs. per b.h.p. being obtained. This compares with a guaranteed figure of .006 lbs.

It is interesting to note, from the published reports of the Diesel Engine Users Association for the years 1929 and 1930 that a power station fitted with Fraser & Chalmers engines obtained the lowest fuel consumption for these years.

MATERIALS HANDLING.

An extensive ship coaling plant has been installed at Dover Harbour for the Southern Railway. This plant, fig. 36, has a loading capacity of 500 tons per hour, the travelling boom loader enabling ships to be loaded speedily at any point alongside the harbour arm, and the hinged telescopic chute facilitating convenient trimming of the coal in the ship's holds. An automatic wagon tippler forms

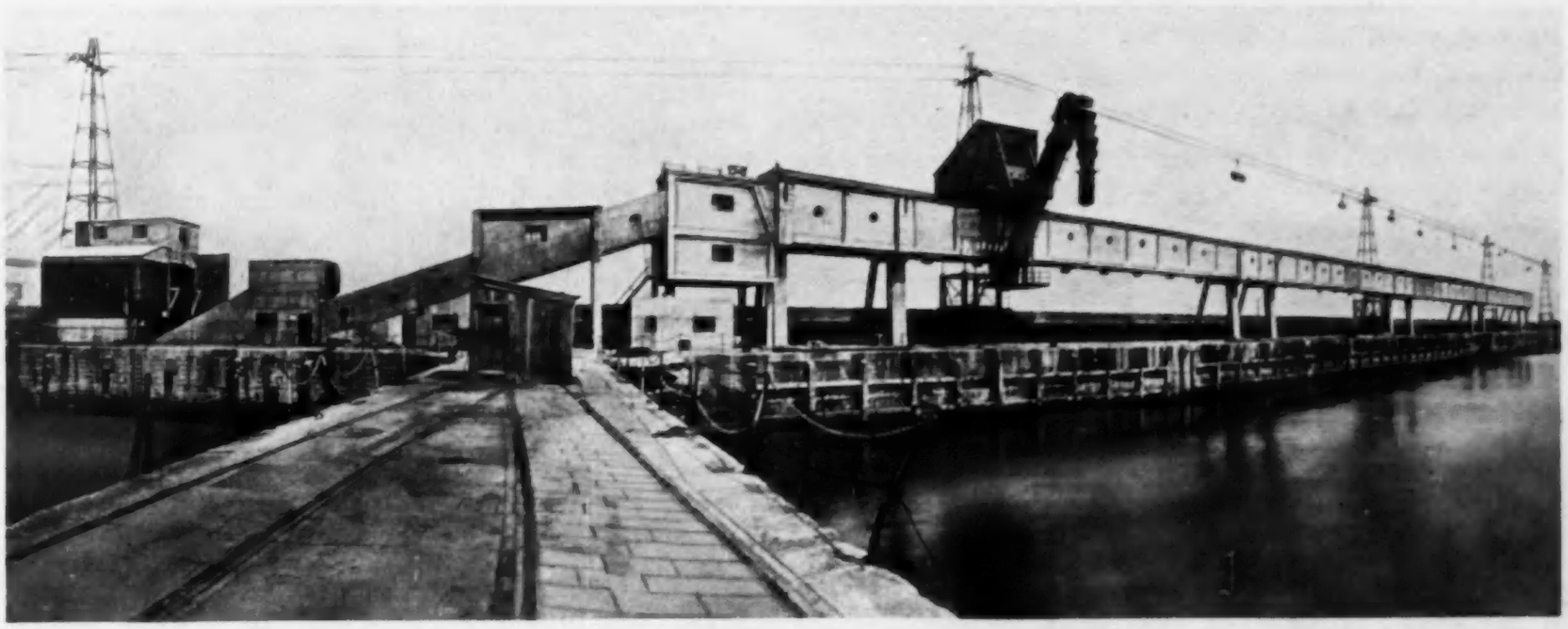

Fig. 36.—Ship coaling plant at Dover Harbour for the Southern Railway, capable of loading 500 tons per hour.

part of this plant, capable of handling 10, 12 or 20 ton trucks, at a rate of 40 per hour.

Following the successful inauguration of an ore handling plant at Takoradi (*G.E.C. Journal*, Vol. III, No. 3, page 157) a plant of a similar nature has been completed in Sweden for the export of Swedish ore. It consists of a scheme of belt conveyors designed in accordance with the Robins system, a wagon tippler and travelling ship loading tower. The contract for this plant was obtained against keen foreign competition.

The coal and coke plants which have been installed at Oldham Corporation Gas Works may be taken as representative of the latest practice for such equipment, and for that reason a brief outline of the methods employed are given below.

The incoming coal for the coal plant is delivered to site in wagons, automatically tipped and weighed, and, if necessary, crushed and delivered immediately to the retort house by an inclined conveyor. Alternatively, it is delivered straight to storage pile

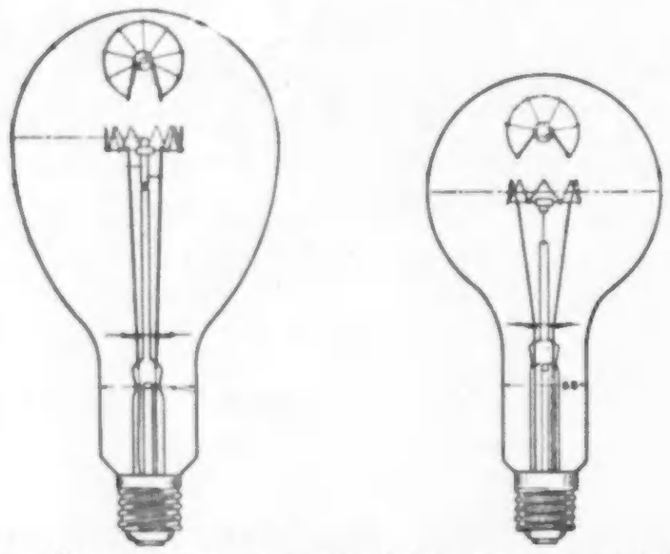

Fig. 37.—Comparison of old (left) and new (right) bulb shapes for high wattage lamps.

until required in the retort house, as coal is not crushed until actually required owing to the more rapid deterioration in the crushed state. Reclaiming from the pile is carried out by a mobile crane and grab feeding into a travelling hopper on the main conveyor.

The long conveyor from the retort house delivers coke to the top of the screen house, under which are the main coke bunkers of 400 tons capacity. The coke first passes through a chute, which enables it either to pass forward to the skip filler, referred to later, or to rotary grizzlies, arranged on the right and left hand sides of chutes, coke from this point flowing into two sections. Coke is graded by means of the grizzlies, two double deck Gyrex screens, and two single deck Vibrex screens, as follows :—

Large coke ..	$+2\frac{1}{2}$ in.	Grizzlies.
Medium coke..	$1\frac{1}{2} - 2\frac{1}{2}$ in.	Gyrex screens.
Nuts	$\frac{3}{4} - 1\frac{1}{2}$ in.	Ditto.
Breeze.. ..	$\frac{3}{8} - \frac{3}{4}$ in.	Vibrex screens.
Dust	$- \frac{3}{8}$ in.	Ditto.

All oversize, if desired, is directed into a large coke hopper by means of a by-pass chute and spiral cast iron chute, which minimises breakage.

Coke is drawn from the 400 ton storage bunkers through 39 openings, 13 of which deliver to railway wagons, 13 to carts and 13 to the travelling hoppers on each of two conveyors. One of these conveyors delivers to an automatic coke skip filler, and the other to an inclined conveyor arranged underneath the bunkers and feeding into the producer feed hoppers in the retort house. Situated at the head end of the latter conveyor is a hopper into which the gravity bucket conveyors may feed in case of emergency.

Considering the coke delivered to the top of the screen house, a conveyor runs forward from this point to the top of an automatic skip loading hopper, which acts as an intermediary between the auxiliary coke storage and the screen house.

The "Webb" conveyor, which is of the power driven overhead trolley type, has been applied to handling problems in a wide variety of industries. Some idea of the possibilities of the system may be obtained by considering the following list of materials and produce which are dealt with: motor car bodies, motor tyres, sheet steel pressings, wooden parts passing through painting and drying shops, wireless sets and component parts, kegs and barrels of syrup, bananas, etc.

LAMPS AND ILLUMINATION.

One of the outstanding achievements which mark the progress of lamp making during 1932 is the adoption of the new shaped bulbs for high wattage lamps, which have been agreed as standard for international use throughout Europe. It is some years since the adoption of similarly agreed standards for what is known as the "Simplified Line" (the range of lamps from 15 to 100 watts inclusive) brought about standardization for the most used types.

So far as high wattage lamps were concerned in the past, provided that the lamp manufacturer confined himself to certain maximum limits for overall length, diameter of bulb and light centre length, he was free to make any size or shape of lamp which suited his own particular trend of design. The result was that the products of no two manufacturers were alike. Some preferred a bulb which was more or less club shaped, others the spherical shape with long parallel neck. Fittings designed for one type of lamp would not always take another, and so the practice created inconvenience both for the manufacturer of the fittings and for the consumer.

After prolonged negotiations between the lamp making authorities of Europe, definite shapes and dimensions were finally agreed upon which embody the best practice, taking into account both appearance and technique, and 1932 saw the adoption

of these shapes as International standards. The difference between the old and new standards as manufactured by the G.E.C. may be seen in fig. 37, and it will generally be agreed that, apart from the advantages of standardization, the new shapes are to be preferred from the standpoint of appearance.

In addition to the foregoing considerations, the new shaped bulb possesses another advantage over the old shape which is of some importance. Users of the old shape have occasionally met with bulb cracks brought about by water splashes, either due to condensation in the fitting or by direct contact of rain drops falling upon that part of the bulb just below the parallel sides of the neck. In the new shapes, the glass runs cooler at this point and there is less danger of cracking.

Simultaneously with the adoption of the new shaped high wattage bulbs, the G.E.C. introduced a further improvement, known as the "fuse-in-lead" construction, designed with the object of preventing a dangerous arc on failure. As the efficiency of lamps is improved, especially in the higher wattages, so the conditions favouring an arc on failure are increased. To circumvent this, a fuse is incorporated in one of the leads within the lamp, which will function should the current exceed a certain predetermined value and thus prevent the damage which may follow a sustained arc on failure of the filament. This fuse forms part of one of the lead wires and is enclosed within a small glass tube, as shown in fig. 38.

During the past year steady improvement has been maintained in the uniformity of lamp performance both in light output and life. This is the result of detailed attention at all points in the course of manufacture. The discrimination between the effects on lamp performance of the various lamp making processes and the relative magnitude of these effects has been helped in very considerable measure by developments in the application of the statistical theory sampling to the test results. The application of statistics to this problem began in 1926 and has steadily grown. During this last year there has been evolved at the Research Laboratories a method* of dealing with this problem which is peculiarly adapted to those cases in which tests have to be made to destruction and which involve considerable periods of time (for example life tests of lamps or valves).

This new method enables those in charge of such tests to make an estimate of whether a batch of lamps is up to quality or not, some considerable time before the test is completed, and in cases of doubt repeat tests can be inaugurated before the first test is completed. It is of interest to note that recently a committee under the auspices of the British Standards Institution has been formed with a view to studying the applications of this statistical method, not only to the control of manufactured products, but particularly as a guide in the drawing up of specifications. The G.E.C. Research Laboratories are taking an active part in the work of this committee.

In the field of lamps for specialised services innovations have been more marked, as is shown by the few examples which follow.

A new 10 volt 10 ampere exciter lamp for sound reproduction has been designed for use on alternating current. The heavy filament holds the heat and the nigresence between the cycles is so slight that the light is for practical purposes as steady as if the lamp were used on direct current.

In the past, due to technical difficulties, it has always been necessary to use 4, 5 or 6 lamps of

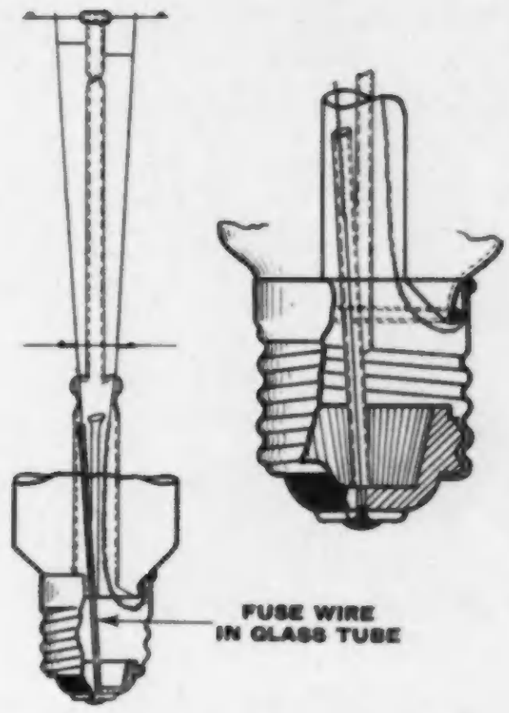

Fig. 38.—"Fuse-in-lead" construction adopted with high wattage lamps.

100—130 volts on traction circuits for the lighting of tramcars, trolley buses or electric trains, with the result that if one of the lamps in the series failed the full series was temporarily put out of action, causing inconvenience and bad lighting in the vehicles.

The new Osram low volt long series traction lamp is rated at 40 volts 40 watts and is made to run in series of fifteen lamps on 500/600 volt traction circuits. The lamp has been fitted with a fuseable cutout which consists of an aluminium strip placed across the two lead-in wires inside the bulb. One of these lead-in wires is insulated by means of a further strip of aluminium with an oxide coating. At 40 volts this oxide acts as an insulator but on the breaking of the lamp filament the full open circuit pressure of from 500 to 600 volts is thrown across the break in the filament, thus causing a permanent breakdown of the insulation of the cutout which automatically short circuits the lamp and allows the remaining fourteen lamps in the series to function.

This lamp is used in conjunction with the special G.E.C. patented short circuiting holder, which

*—Paper in course of preparation by J. W. Ryde of the G.E.C. Research Laboratories, Wembley, England.

enables the lamp which has failed to be removed from the circuit without interfering with the remaining lamps in the series, and at the same time prevents any possibility of arcing taking place in the lamp holder during the removal or replacement of lamps.

The main advantages of such a system are (1) more efficient lighting of the vehicle, (2) the low voltage of the lamp and its method of construction ensure that it shall be much more efficient and reliable, and (3) a large reduction in maintenance costs.

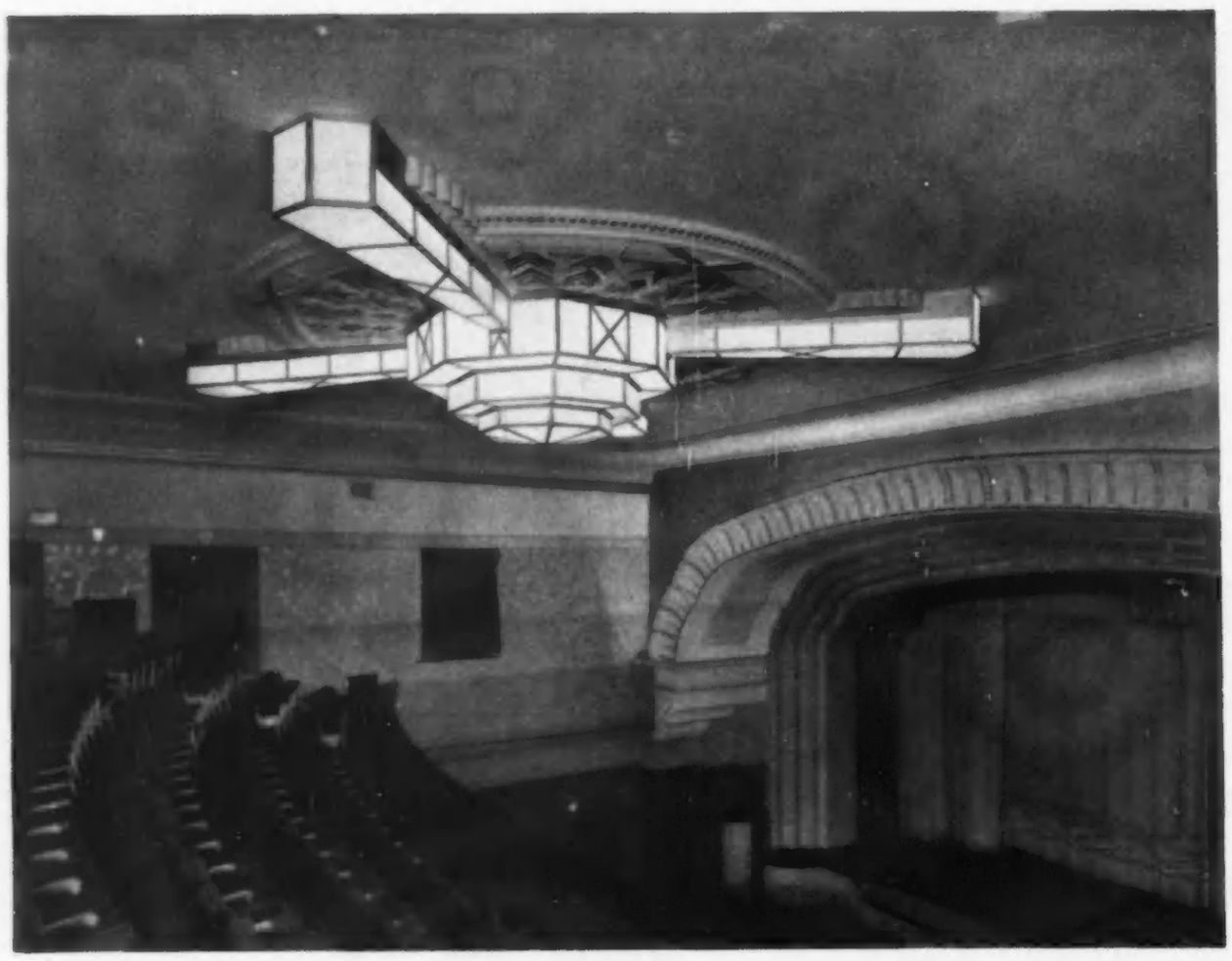

Fig. 39.—Typical modern lighting unit in a cinema theatre.

A high efficiency lamp rated at 500 watts is now made ; its primary purpose is to enable amateur photographers to take photographs in their homes at night. These lamps are made for all standard voltages. They give just over 20 lumens per watt ; naturally at this high efficiency their life is comparatively short, being in the region of 100 hours. However, as they are only burnt for at the most a minute at a time, this means that about 6,000 exposures can be made with one lamp. A special portable reflector has been designed for use with these lamps.

An exceptionally small 10 kW lamp has been produced for cinema studio work with the filament mounted in the form of a flat grid. The production of a lamp of such a high wattage with a small bulb has been fraught with many difficulties, one of the chief being to find a glass capable of withstanding the enormous heat generated. But a suitable hard glass has now been found and the new lamp which is only about 12 inches in diameter provides film producers with a light source of the greatest brilliance ; yet the lamp is of such a size that it can be worked in a "set" as easily as the smaller sized spotlights.

The tendency in illumination towards greater use of scientific design has definitely advanced during the past year. In decorative lighting more particularly, the proportion of enquiries which have asked for a lighting scheme which should be scientific as well as decorative (as compared with a purely decorative scheme) has steadily increased. In the same manner the tendency towards the use of indirect lighting systems and architectural built-in systems has become more pronounced. The very much cheaper rates for electric current, which are available in many districts to big users of light, have made this form of lighting a more practical proposition.

These tendencies naturally involve the closest co-operation between the architect and the electrical engineer. In fact, so great has become the importance of this co-operation that the G.E.C. has recently presented a prize for competition amongst students taking the diploma of the Incorporated Institute of British Decorators.

A matter of national interest during the year has been the complete change-over from foreign to British illumination glassware. In bringing about this most welcome change the Research Laboratories were able to give valuable help in improving the technique of glass manufacture for illumination purposes. As a result G.E.C. illumination equipment is to-day entirely made in England.

The show window reflector affords an interesting example of improvements effected. The efficiency and effectiveness of such a reflector depend upon its reflecting surface, its contour, and upon the method employed for the elimination of striations. The Gecoray reflector has always been of silvered glass on account of the high reflection factor of this material. But with many forms of smooth reflector there is a marked tendency for bright streaks to occur on the surface illuminated, and it is for this reason that the Gecoray reflector has a fluted surface. During the past year the Laboratories have undertaken the study of the action of flutings, and based upon the results of this investigation, a range of Gecoray show window reflectors incorporating new flutes has been produced. Light output measurements on the new reflectors have shown them to have extremely high efficiencies, and illumination tests have proved that the light distribution is such as to produce very effective lighting in the windows.

In connection with the investigation of flute formation, it was necessary to determine how nearly the manufactured samples conformed to the theoretical design. To assist with this determination and with the general study of the passage of the light through the medium of the glass itself, a special ray-path apparatus was developed. By means of a narrow beam of light, this apparatus traces out the reflections and refractions of a ray of light as it passes into and out of a reflector, and with its aid, sources of inefficiency in the various designs were discovered and eliminated. The apparatus has since been used with considerable success in the study of the passage of light through refractors as well as reflectors, and much valuable information has been obtained.

The results of mathematical studies on the theory of light scattering by diffusing media have been applied to G.E.C. opal glassware with a resulting improvement in diffusing power and efficiency. Following these investigations it is now possible to ascertain from tests on a small sample of glass the optical properties of the opal and from the constants so obtained to foretell such qualities as minimum thickness for complete diffusion of the light source and the efficiency of a globe made from the glass at any thickness. Opal glasses are now so examined as a standard routine, and such examinations together with rigid works tests for efficiency and diffusion have resulted in a marked improvement in G.E.C. opal glassware. It has actually been possible to produce a totally enclosed glass unit, complete with metal canopy and a glass globe, which will completely diffuse the light from the lamp inside the fitting, while absorbing as little as 20 per cent of the light from the lamp.

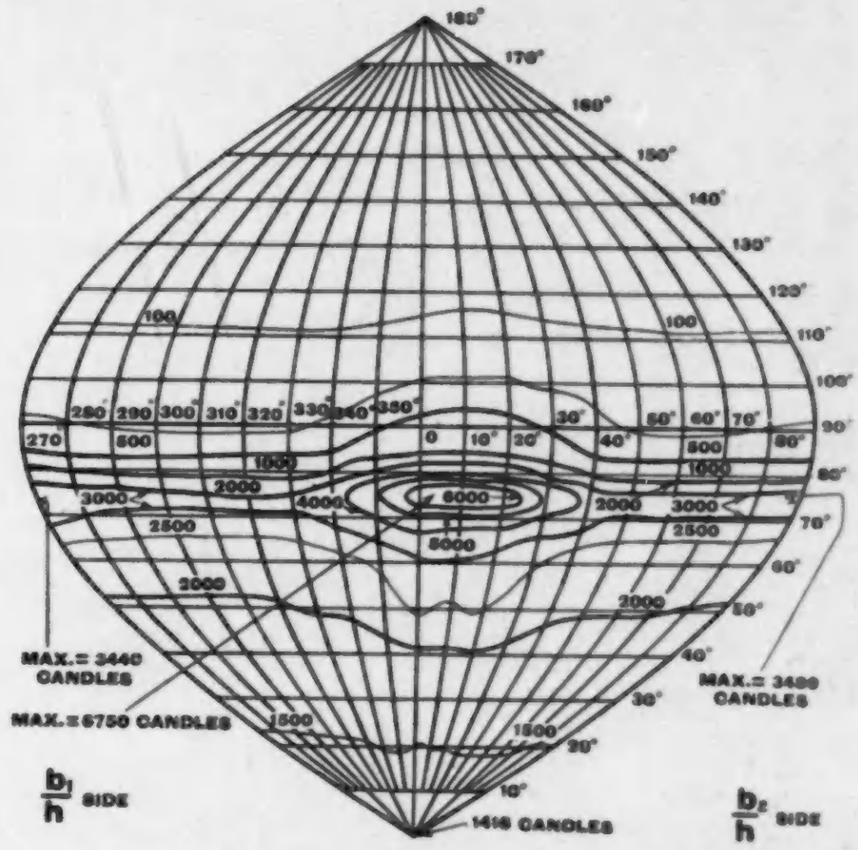

Fig. 40.—Iso-candle diagram of 1,000 watt Wembley lantern, equipped with asymmetric 2-way non-axial dome reflector.

As already mentioned, there is an increasing tendency among architects to incorporate lighting fixtures as an integral part of decorative schemes, but there is an indication that the adoption of the pronounced modernistic type of design is not generally favoured.

Luminous glass cornice lighting, built-in lighting forming an architectural ceiling motif, and luminous features forming part of the decoration of wall surfaces, columns, etc., are being adopted as methods of illumination, but the lighting efficiency of such installations depends upon the spacing of the lighting fixtures in relation to the area requiring illumination, and the careful calculation of the wattage of lamps required.

The utilization of glass panels as a light diffusing medium is steadily maintained. Rolled sheet glass decorated and obscured in a variety of ways by means of sandblasting and acid etching is being widely adopted in preference to the heavy moulded glass of Continental manufacture, the use of which shows a steady decline. Flashed opal glass of various delicate tints is superseding the colour-spray tinted obscured glass to a considerable extent.

These changes all tend to emphasise the unstable nature of modern decorative illumination. This art is passing through a transitional period and the ultimate developments will be largely influenced by innovations in electric light sources. Modern decorative lighting ideas have created a demand for a continuous line of light, but whilst this has been met to a considerable extent, questions of economics, reliability and efficiency, will be the deciding factors in establishing this form of lighting on a permanent basis.

Fig 41.—Lighting of the Mall, London, employing the constant current series system.

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Regarding the design of individual lighting units, the soundly constructed, metal framed, panel type fitting is generally favoured for the larger fixtures. It is also noteworthy that in many modern

Fig. 42.—The lighting of Worcester Bridge is as efficient as it is decorative.

buildings, based on classic architectural lines, the design of the lighting fixtures combines modern lighting practice with traditional decorative treatment, as exampled in the fittings installed in the Marble Hall in Cardiff City Hall and the Council Chamber, Beckenham Municipal Buildings.

The ranges of Wembley lanterns for street lighting have been improved by the conversion of the ventilated to the non-ventilated type. Savings in upkeep have been effected and a general change-over in design has made all types of lanterns more easily handled, while the great advance in the production of English made glassware has made possible an All-British refractor, entirely re-designed by the Research Laboratories in types to meet every condition demanded by road widths and the possible positions of posts. The light distribution has been so much improved that not only has more use been made of the light flux, but the appearance of the road has been materially improved. All the smaller ranges have been entirely re-designed to meet the growing demand for the re-lighting of side streets, arterial roads and villages. Simplicity and ease of handling from a wiring point of view have been given full attention, while the simplification of the design has led to units of lower price without any decrease in efficiency or reliability.

One example of these re-designed lanterns is furnished by the new reflecting unit for use in side streets where long spacing and low wattage are demanded. This new unit produces a higher mid-span intensity than any other type, and owing to the peculiar texture of the glass from which it is made, gives the effect of less glare in spite of its increased efficiency.

Amongst the routine tests of efficiency and light distribution made upon lighting units during the year, one set of tests is particularly worthy of mention. It was necessary to determine in detail the performance of the new symmetric and asymmetric dome refractors used with the Wembley street lighting lanterns. These data are required by all designers when calculating the illumination which will be obtained in a given installation. Clearly the figures obtained by measurement must represent an average result so that the calculated values for any installation will conform as closely as possible to the illumination which will actually be obtained when the fittings are erected. With this in mind, it was necessary first to select and then to obtain a sufficient number of photometric readings for the results to be truly representative. In the

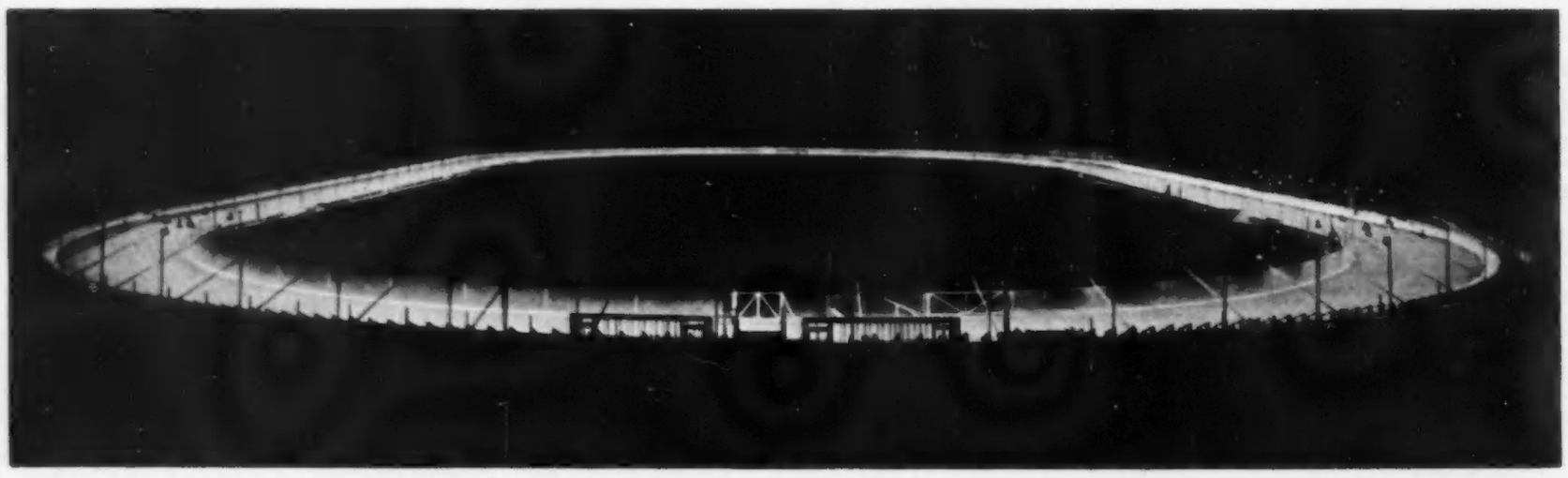


Fig. 43.—A picture of the White City greyhound racing track, when half the lighting of it was converted. Note the visible lights and shadows on the right, and their absence under the new system on the left.

case of each of the asymmetric units, about 2,000 readings had to be taken on the lantern and the mean performance diagram was plotted from these results. Fig. 40 shows a typical diagram for a 1,000 watt Wembley lantern equipped with an asymmetric 2-way non-axial dome refractor. It will be seen that the customary polar curve is not used for the asymmetric units, as the light distribution is different in each vertical plane, but an iso-candle diagram is employed. The web on which the lines are plotted is a representation of the space around the lighting unit divided up by angular co-ordinates similar to lines of latitude and longitude, and the iso-candle lines upon it indicate equal values of luminous intensity. With such a diagram, the illumination at any point in a street from any arrangement of units can be determined.

Some notable street lighting installations have been completed during the year and reference may be permitted to a few of the more important.

Fig. 45.—Aerodrome type floodlights used to illuminate the Scarborough Open Air Theatre.

The re-lighting of the Mall has been effected by substituting for the original arc lamps, Wembley lanterns equipped with a special type of lamp of 1,250 watts. This installation has been designed to meet the conditions demanded on that particular site, namely, the conversion of series arc lighting to constant current series system without alteration to the existing wiring in the columns. It was for this reason that the special lamp of 1,250 watts was developed by the Osram Lamp Works which ensured the maintenance of a high efficiency without overloading the existing cables.

Fig. 44.—Interior of bacon factory showing modern system of illumination.

A complete changeover of the whole of the main street lighting of Scarborough from gas to the new non-ventilated asymmetric non-axial refractor type Wembley lantern is another tribute to the efficiency of this system, as Scarborough has always been claimed as the "best lighted seaside resort in the country."

Other large installations have been carried out in Bromley, Woking, Dulwich, Kensington, Hastings, Norwich, Woolwich, The Great West Road at Heston, and at Hull where the new model open type refractor lantern is gradually replacing gas. Docks which have been lighted with the P.L.A. type lantern include those at Southampton and Sunderland, while bridges at Worcester, fig. 42, and Lambeth have been the subject of illumination schemes presenting features of interest.

Amongst other applications of illuminating engineering there has been considerable activity in the lighting of greyhound racing tracks. To meet this demand a unit has been designed which has very great advantages over the type of equipment previously used for the purpose.

A reference to fig. 43, showing the White City Greyhound Track, half illuminated by the new G.E.C. system and half under the old system, will immediately show the advantages of this new design. The principal of these are the concentration of light on to the actual track and saving of wastage on to the area outside the track, the complete absence of light sources visible to the spectators, and the elimination of the skirt glare which is experienced with the ordinary type of enamelled reflector. Combined with these advantages the actual illumination on the track is very considerably increased in

spite of a 10 per cent reduction in wattage consumed, while the installation of only one unit per span in place of the three originally installed means considerable reduction in installation charges.

Fig. 46.—Many of the ancient buildings on the Acropolis, Athens, are now floodlighted. This view shows the Parthenon.

Other special units that have been developed include an indirect lighting unit for the illumination of halls, offices and similar situations, based on the reflector which has proved so successful for direct lighting at the Port of London. The same reflector has also been developed for indoor use as a factory lighting unit. Its high overall efficiency and wide spread, combined with the comparatively low angle of cut-off, have rendered it very successful for the purpose. Examples of the use of these units are shown in fig. 44.

An addition to the range of G.E.C. floodlights

Fig. 47.—Effective lighting standards are erected outside the new Parliament Buildings, Belfast.

takes the form of a super-quality floodlight, for railway yard floodlighting and similar purposes. This unit has a number of mechanical contrivances designed to give the utmost ease in setting and maintenance, including a system of internal wiring to a fuse-box set in the base which makes the unit entirely self-contained. Another addition is a unit

used with great success at the Scarborough Open Air Theatre (fig. 45), which is also particularly suited for protective purposes, such as preventing the approach of unauthorised persons to enclosed premises.

A floodlighting installation which has attracted much attention is that which illuminates the whole of the ancient buildings on the Acropolis at Athens. Many extremely beautiful effects are produced by the lighting as is shown in fig. 46.

Space forbids more than passing reference to the many schemes of illumination installed in churches, picture galleries, show windows, hospitals, film studios and public buildings of every kind. It is desirable, however, to devote some attention to certain specialised activities in the field of illumination.

A new portable reflector for amateur and professional photographic lighting has been produced to work in conjunction with the special 500 watt photographic lamp described earlier in this article; also a number of new designs of studio lighting equipment have been produced including a range of 2 kW projectors, a 5 kW projector and a 2½ kW floodlight.

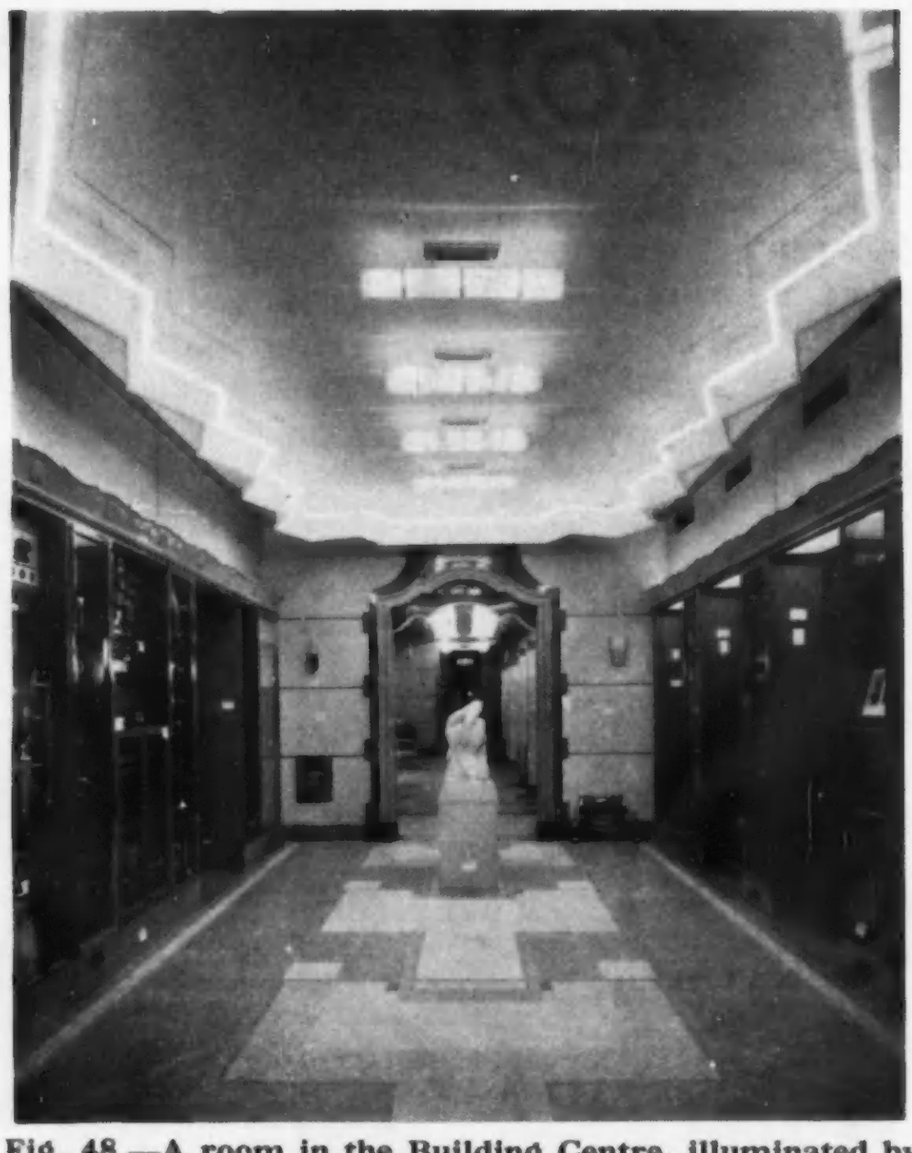


Fig. 48.—A room in the Building Centre, illuminated by "Claudegen" sunlight tubes.

In aerodrome lighting, flashing neon beacons have been supplied both at home and overseas, and the first neon tube fog landing unit in the world has recently been installed at Croydon Aerodrome.

The neon sign business of the company which is undertaken by Claude-General Neon Lights, Ltd., has enjoyed considerable expansion mainly due to

the increased services and bigger variety of effects available, and the more efficient and reliable nature of the equipments. A simple flashing device with no moving parts has been the means of enhanced attractiveness to a number of pictorial displays.

Perhaps the most interesting development in luminous discharge tubes has been the advent of the "Sunlight" and "Daylight" installations. The "Claudegen" Sunlight tube emits a light of golden peach colour, which approximates closely to sunshine and is suitable either for interior or for exterior illumination. The distinctive glow makes this tube particularly suitable for the purpose of outlining buildings, where it forms a conspicuous decoration.

For the purpose of interior illumination the combination of large diameter ($1\frac{3}{4}$") tubes and a low apparent brightness, although the luminous output is actually 150 lumens per foot run, permits the tube to be viewed at close quarters without discomfort to the eyes, and thus for these inside installations the source of light need not be concealed. On the contrary it may be used with advantage to

Fig. 49.—A well-known luminous tube display at the London Pavilion.

emphasize and harmonize the decorative features of the room.

This form of illumination is shown in fig. 48, which gives a view of one of the rooms in the Building Centre, New Bond Street, London. The Building Centre is a permanent exhibition at which may be inspected, under the best possible conditions, everything appertaining to the construction and equipment of buildings. Naturally the latest forms of illumination by electricity present one of the most interesting features of the exhibition.

The latest installation of nearly 20 kVA loading,

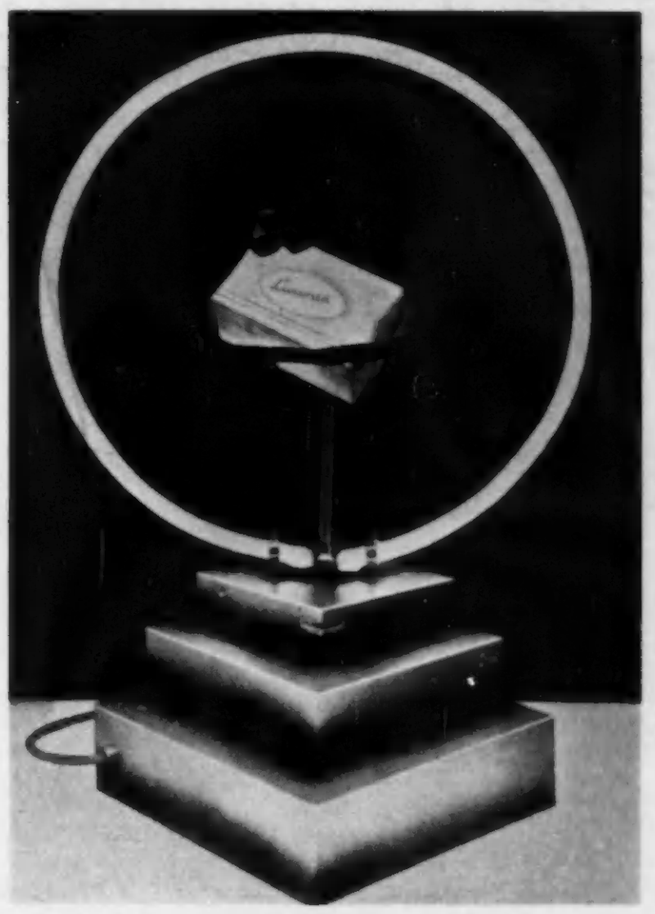


Fig. 50.—The new "Ripple" effect in discharge tubes is now being employed commercially.

makes use of the tube in the manner described above for the illumination of a restaurant. The pleasing colour, closely resembling sunlight, makes the surroundings very cheerful and is, therefore, eminently suitable for situations where such an atmosphere is required.

Installations of "Claudegen" Daylight tubing are of particular interest because of their colour-matching properties. In this case the light emitted is white, and when measured with a photo-spectrometer the colour is found to fall within the north light spectrum. It is therefore an ideal illuminant for textile and other industries where colours and textures are handled, since such an installation can be used as a standard for matching regardless of external conditions of light.

In large factories it is usual to have a permanent installation utilizing the "Daylight" tubing, but a self-contained portable unit has been evolved to meet other circumstances where a permanent installation would not be suitable or desirable. An important point with regard to both "Claudegen" Sunlight and "Claudegen" Daylight installations is that they have a natural power factor between 0.7 and 0.8 in contrast to the lower figure of ordinary luminous tube installations, commonly known as Neon.

Mention must also be made of the "Cleon" portable window or display sign, which has been developed to such an extent that it is now being manufactured on mass-production lines. It consists

of a bakelite case housing the transformer electrodes and high-tension connections. In the "Cleon" sign the announcement is etched into the plate glass front, around which is a luminous discharge tube illuminating the message by refraction.

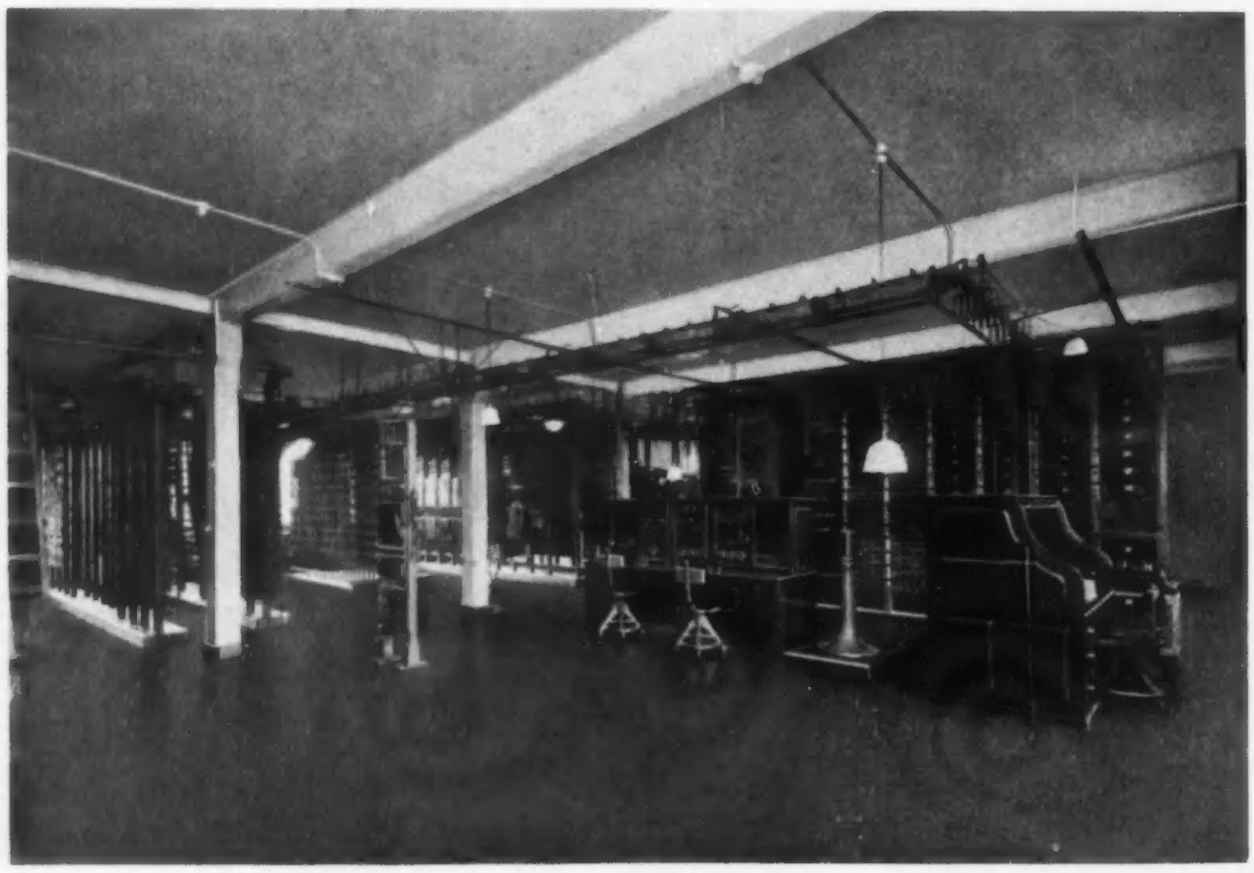


Fig. 51.—Telephone repeater station at Gloucester.

A further development with this device is the use of fluorescent lacquers, whereby it is possible to present the announcement in various colours, while it is illuminated by a surrounding tube emitting

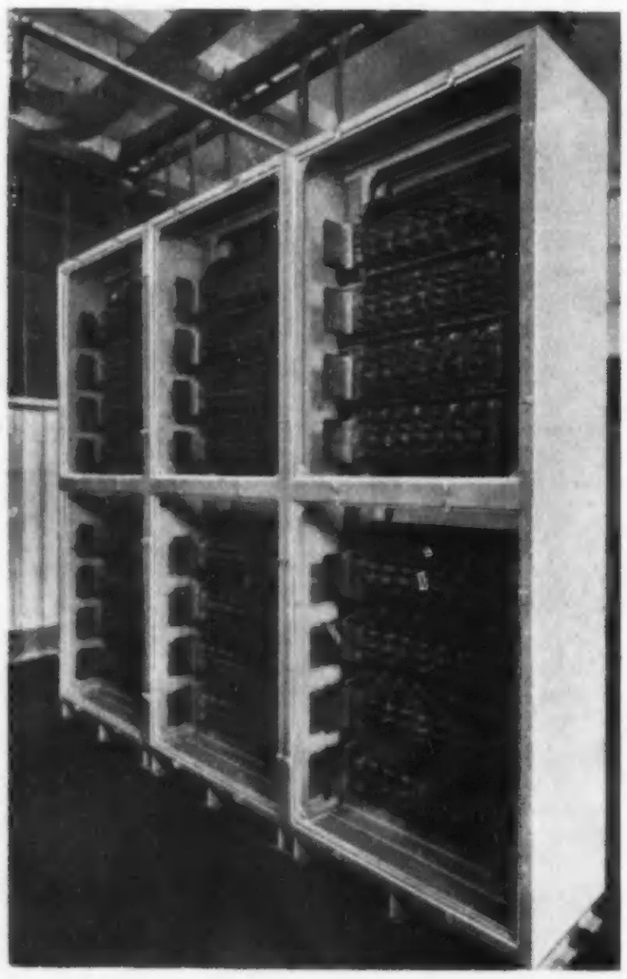


Fig. 52.—Cord circuit repeater equipment at Birmingham.

a light of yet another colour. This method of changing the refractive index has proved already to be highly satisfactory, but it is not yet in its final form.

The application of "Ripple Neon" to window display, fig. 50, is a development that has awakened widespread interest. The "Ripple Ring" now being marketed, with its continual movement of a stream of light, provides a most dynamic addition to any window display, and is already being adopted by many national advertisers.

Many very prominent luminous tube displays have been installed in London and the Provinces. One on the Empire Theatre, Leicester Square, which presents red, blue, green and gold, is very effective. Another at the London Pavilion (fig. 49), embodying an animated pictorial design which includes a troupe of dancers, is illuminated in Neon tubing. It is now possible for theatres and cinemas to make their feature announcements in Neon tubing by means of interchangeable letter signs. One installation of this nature consists of 48 letters, 3 feet high which have been changed every week for some months past.

TELEPHONES AND WIRELESS.

At a time when several countries, in consequence of the disturbed economic conditions now prevailing, report considerable decreases in the number of telephones, it is gratifying to learn of the continued progress of the telephone service in Great Britain. Whereas, in the matter of telephone development this country has hitherto advanced at a comparatively slow rate, figures for 1931-2 reveal a net increase of 84,000 stations, the largest recorded in any country in the world for the same period.

From a technical aspect also there have been many achievements during the year under review, notably the introduction of the Teleprinter Exchange Service and the rapid strides made in the extension and improvement of the trunk network. A considerable increase has occurred in the number of "zero" transmission loss circuits between the principal cities, while the no-delay or "demand" system of trunk working, under which almost immediate connection may be obtained with distant towns, has also been further extended.

It would be difficult to give a complete picture of the amount of work involved, both in research and manufacture, in carrying out the many contracts undertaken by the Company for the supply and installation of trunk telephone equipment, but some idea of the modern apparatus with which the numerous repeater stations throughout Great Britain are now equipped may be obtained from fig. 51, showing representative equipment installed at Gloucester. Of particular interest is fig. 52 illus-

trating the new automatic switchgear at Birmingham, operating in conjunction with a manual switchboard at which large numbers of trunk lines are concentrated. By means of this equipment, when trunk connections are established, cord circuit repeaters are automatically inserted as required, the appropriate line balances found, and the necessary gain selected.

The successful introduction and application of the "zero loss" circuit, by which the quality of speech over long distance lines of communication is so greatly improved, has been described as the outstanding achievement in land-telephony for many years. In this connection much development work has been carried out, particularly in apparatus design. Examples of improved components of which increased use has been made are to be found in the "echo suppressor," employed to stabilise circuit conditions, and in the "attenuation equaliser" necessary to effect correction for the unequal attenuation of different speech frequencies in transmission, and so preserve the highest quality of speech over long repeatered lines.

In the conversion of the switching system from manual to automatic, further progress is to be recorded, particularly in the larger cities where the Director system is being introduced. Much has been accomplished in the standardisation of automatic plant for large telephone exchanges and in the effort towards more simple and regular construction. A typical modern exchange is that at Hither Green, London, fig. 53, which will be seen to employ a new and improved type of rack construction.

The problem of providing a first-class telephone service in thinly populated areas, which was partly solved by the adoption of the small rural automatic exchange referred to in the *G.E.C. Journal*, Vol. I, No. 4, has received further attention, resulting in the development of a second type giving a capacity of 200 lines as against 100 lines in the case of the first model. The standard unit for the larger exchange is again designed to serve up to 25 subscribers and to give a full local automatic service with connection by junctions to the main system. Any number up to eight of these units may be lined up together to form a complete installation of the unattended type, requiring only periodic attention for the purpose of battery charging and routine inspection.

A serious problem which has for some years confronted telephone administrations and has latterly become more acute owing to the rate at which developments are taking place, is the growth in the variety of types of apparatus employed in both manual and automatic exchange systems.

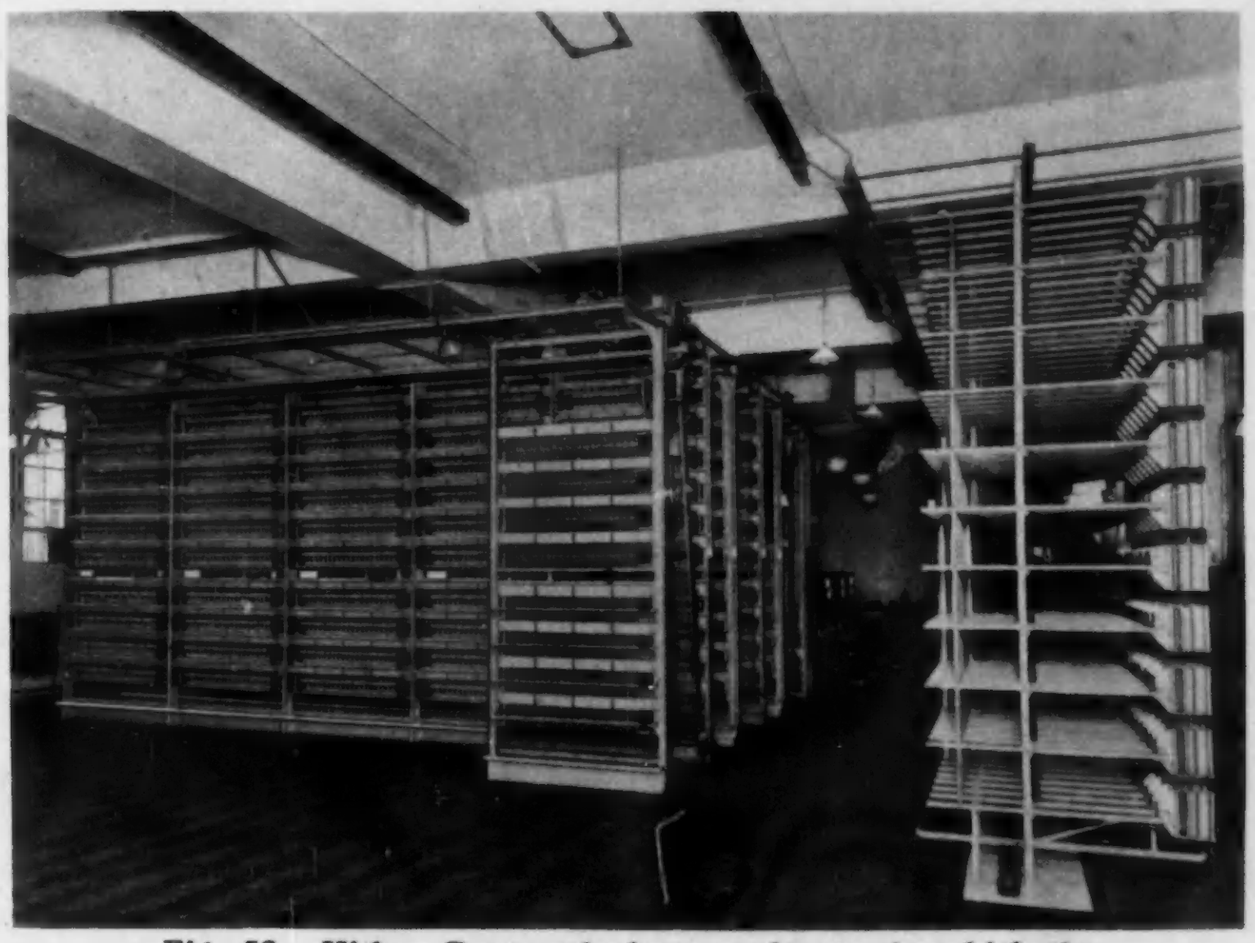


Fig. 53.—Hither Green telephone exchange, in which the Director system is employed.

Although the British Post Office has led the way in a policy of standardisation which has received support in many other countries, more intensive

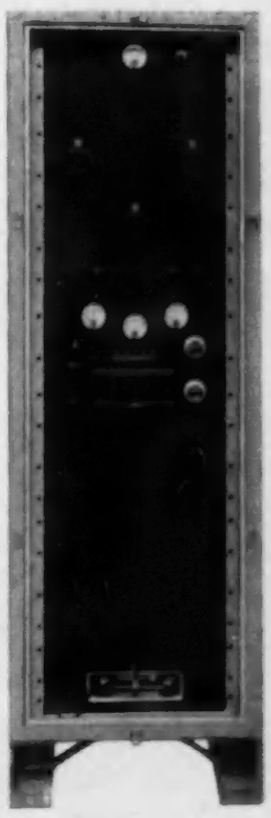


Fig. 54.—Single channel carrier current set, used for communication over existing lines.

Fig. 55.—Voice frequency equipment for the conversion of direct current signals into voice frequency impulses.

work in this direction has recently been found necessary. Innumerable types of relay, for instance, have come in to common use and since this component figures so prominently in all telephone

systems, an effort has been made to place some limitation on the variety to be employed in the future. A measure of success has already been achieved and the past year has seen the wider application of two improved telephone relays which it is

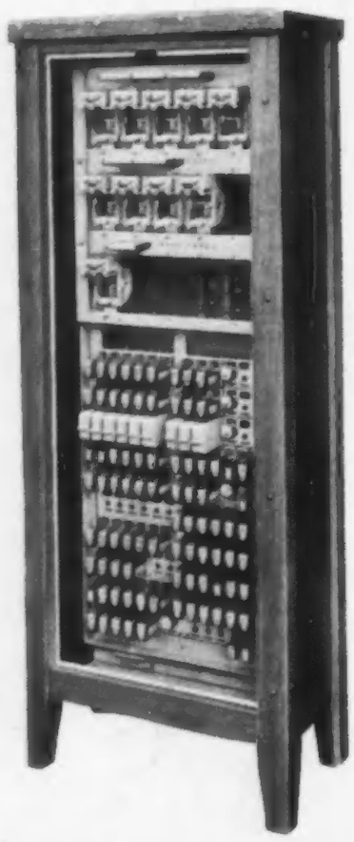


Fig. 56.—Train describer instrument cabinet at St. Enoch's Station, Glasgow.

hoped will gradually supersede a number of existing designs. One is known as the "Minor" type, developed for use in manual circuits and in circumstances demanding only a simple relay, while the other—the "Major" type—is intended to meet the majority of the more severe operating conditions associated with automatic working.

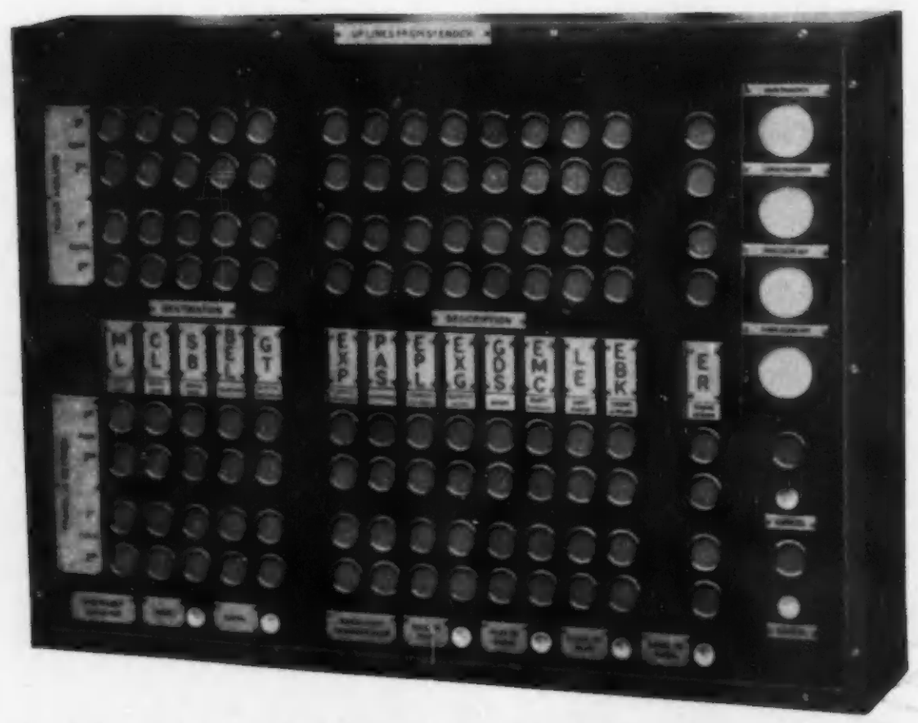
Carrier communication systems, for providing additional channels over existing lines, have been the subject of continued research. Although their use in conjunction with the public telephone service has not developed so rapidly as in other countries where distances are greater, they may be introduced in the near future on short lines in connection with the extension of the "demand" trunk service and also on the main underground telegraph routes

which are about to be loaded for voice frequency and carrier working. The economic advantages of employing carrier circuits has quickly been realised and with a view to meeting the growing demand several new types of carrier set have been developed. A typical example is given in fig. 54, illustrating a single channel set recently installed by the London and North Eastern Railway on one of their principal routes.

There has also been an extension of the use of carrier equipment on power distribution networks but more particularly for feeder protection purposes. While considerable progress is to be recorded in the design of systems whereby E.H.T. transmission lines may be used also as channels for speech and control circuits, their adoption has not been so general in this country as abroad, chiefly on account of the very complete network of Post Office lines already existing.

An outstanding example of the use of such lines for telephone and remote indication purposes is to be found in the very comprehensive schemes adopted by the Central Electricity Board for various sections of the "Grid." Owing, however, to the nature of a telephone line, which does not always provide a D.C. loop, it has been necessary, in designing the communication networks for different areas, to adopt voice frequency signalling. Typical voice frequency equipment for the conversion of direct current signals into voice frequency impulses and *vice versa*, for transmission over telephone lines is shown in fig. 55.

In the Central England Area of the grid system, for which the G.E.C. is supplying the whole of the supervisory gear in addition to voice frequency and auxiliary apparatus, the communication network has made rapid progress. Equipment has been installed throughout the entire area, bringing every grid station under the control of a central office in Birmingham. In addition to giving telephone



Figs. 57 and 58.—Train describer operating and indicating boards at St. Enoch's Station, Glasgow.

facilities, it provides for the complete centralisation of all oil switch indications, meter readings, etc., and represents one of the most interesting of modern developments in this field. Supervisory control systems of smaller types have also been more

extensively applied, and complete schemes developed for the centralisation of control of all kinds of power equipment.

RAILWAY SIGNALLING.

A most interesting application of automatic telephone apparatus to railway signalling is provided in the automatic handling of train descriptions in association with colour light signals.

The most comprehensive scheme of train describers yet developed in this country has been manufactured during the year for the L.M.S. Railway and provides for describing all types of traffic in and out of St. Enoch terminal station, Glasgow.

As the entire area around St. Enoch has been resignalled and fitted with colourlight signals and track circuits, it is now possible for several trains to be in section between St. Enoch and any of the succeeding cabins on the line. Clearly the old systems of describing by code bells or telephonically would place a severe strain upon the signalman's memory, whereas the new scheme provides storage for the maximum number of trains that can be allowed in the sections.

Three types of instruments are installed, terminal transmitters, re-transmitters for intermediate cabins and terminal receivers. The operating and indicating instruments are arranged for shelf and overhead mounting (figs. 57 and 58 are two of the former). The control apparatus, which has involved extensive circuit design, comprises telephone type switches and relays mounted in teak cabinets (fig. 56), and has been designed to operate over two line wires between a transmitter and its associated receiver. The description and destination of trains are set up on transmitters by depressing code keys adjoining the appropriate code labels, the set up being checked

Fig. 59.—Stubless loading coil pot of the buried type dismantled ready for jointing to the armoured cable.

by the illumination of code lamps; the code as set up, is then transmitted by depression of a transmit key.

These codes are stored and displayed at the receiving end, the display being effected by the illumination of lamps adjacent to code labels, and arranged in columns for 1st and 2nd trains with separate columns for each section of line. The indications are automatically transferred to other sections according to which route is taken by the

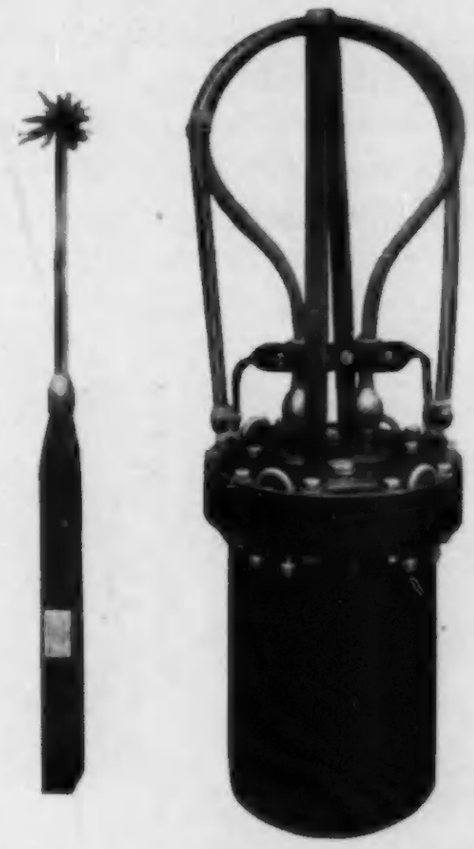


Fig. 60.—Comparison of new manhole loading unit (left), containing 32 coils, with earlier type of similar coil capacity.

train, and are finally cleared from the system by the operation of the appropriate track circuits with the correct setting of signals. At intermediate points codes are retransmitted forward without setting up afresh by operating the re-transmit key for the required line and indication.

A number of auxiliary features have been incorporated to provide for shunting moves, describing the several destinations of coupled light engines from the engine sheds, and allowing for the interpolation of trains from the relief siding. Provision is also made for cancelling codes that have been transmitted, for warning lamps, and manual transfer and clearance of indications in the event of track circuit failure. The whole system is flexible and comprehensive, and represents a further step in their application to railway signalling.

LOADING COILS FOR TELEPHONE CABLES.

Since the introduction at the beginning of the century of loading for telephone cables by adding high quality inductances in series with the line at fixed intervals, little alteration in the practical methods of manufacturing and installing loading coil pots has taken place until very recently. The earlier type of loading coil unit consisted of a number of large coils, each weighing several pounds, assembled inside a massive cast iron pot fitted with two stub cables for connecting to the telephone line. The total weight was thus as much as one or two tons, and cranes and lifting tackle were required to

install the coils in large manholes specially constructed for the purpose. Such disadvantages naturally limited the use of loading to main line cables where the highest quality of transmission was essential, but it has long been realised that the loading principle could be very advantageously applied to all wire communication circuits if the practical difficulties could be overcome.

The problem of reducing the size and weight of loading pots has been fully investigated in the Loading Coil Department at the Salford Electrical

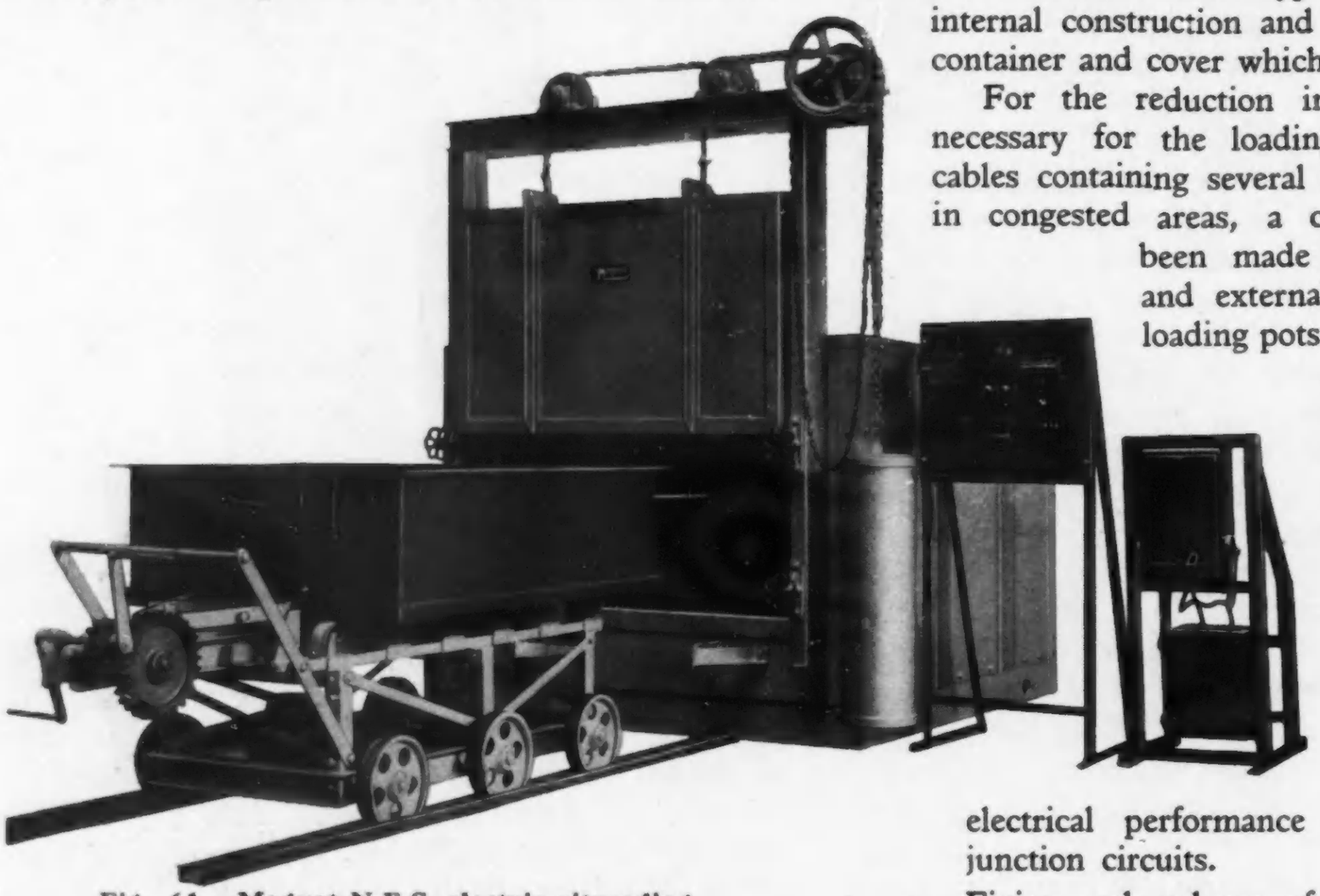


Fig. 61.—Magnet N.F.S. electric nitrarding installation (Nitralloy process).

Instrument Works with the result that loading units containing over a hundred coils have been produced which are portable and whose linear dimensions are not appreciably greater than those of a large cable joint. Such loading units can be installed in cable racks in manholes, or in very small space elsewhere, and thus the use of loading has been extended to include practically any telephone circuit of suitable length.

The first extension of the use of loading for circuits other than main trunk lines took place last year when special loading pots containing small new Gecalloy coils were developed for use on the London-Brighton aerial cable (*G.E.C. Journal*, Vol. III, No. 1, page 26). A further development during 1932 which has caused considerable interest, is the loading of the Pirelli - General experimental armoured telephone cable between Cambridge and Kings Lynn, employing a new type of loading coil container known as the "Buried Stubless Pot." Great constructional economy is effected in both cable and coil installation; the cable is drawn directly into the ground by the side of the road by means of a special moledrainer, and thus dispenses with the use of earthenware ducts. The new loading pot is buried without the use of manholes or other construction except a small concrete raft on which the pot stands. A photograph of one of these pots dismantled ready for installation is shown in fig. 59, the jointing being made to special high-insulation leads in the top of the pot. Several features of the earlier manhole loading pot have been incorporated in this new buried stubless type, especially regarding internal construction and the heavy cast-iron container and cover which resist corrosion.

For the reduction in size of container necessary for the loading of large junction cables containing several hundreds of circuits in congested areas, a complete change has been made both in the internal and external construction of the loading pots. The very light and compact design of these new containers which is mentioned above, is mainly due to :—

1. The production of specially small coils each weighing only a few ounces, but of adequate electrical performance for the loading of junction circuits.
2. Fixing each column of these coils and their connections in square section sheet-iron tubes and sealing them to give mechanical strength combined with permanent electrical properties.
3. Assembling these units into a lead-lined brass container fitted with either one or two stub cables, or else constructed so that the main cable may be jointed inside the lead case.

In this way a flexibility has been added to loading coil manufacture and the problems of installation and jointing have been greatly minimised. An idea of the advantages gained by the introduction of the manhole loading unit can be obtained from fig. 60 which shows one of the new units for 32 coils compared with the earlier type of cast-iron loading pot for the same number of coils of suitably small size. It will be seen from the illustration that the installation problems are greatly reduced by the adoption of the new method of encasing coils. The weight of this 32-coil unit is only 40 lbs. or nearly one twentieth of that of the cast-iron pot, and the length is 2ft. 7ins. to the stub cable connection. The principles incorporated in this design can also be used for larger coils, provided the total weight

is limited to that which can easily be carried in the lead covered type of case.

For loading appreciably more than one hundred circuits in one cable, the coils can be potted in two or more lead-covered containers, and connections made through a multiple joint. Alternatively, there is also a considerable saving of space compared with earlier methods of loading if the new type of internal construction is applied to a single rectangular section loading pot with a case of welded steel.

INDUSTRIAL HEATING.

During the early part of the year arrangements were made for the manufacture of Witton high

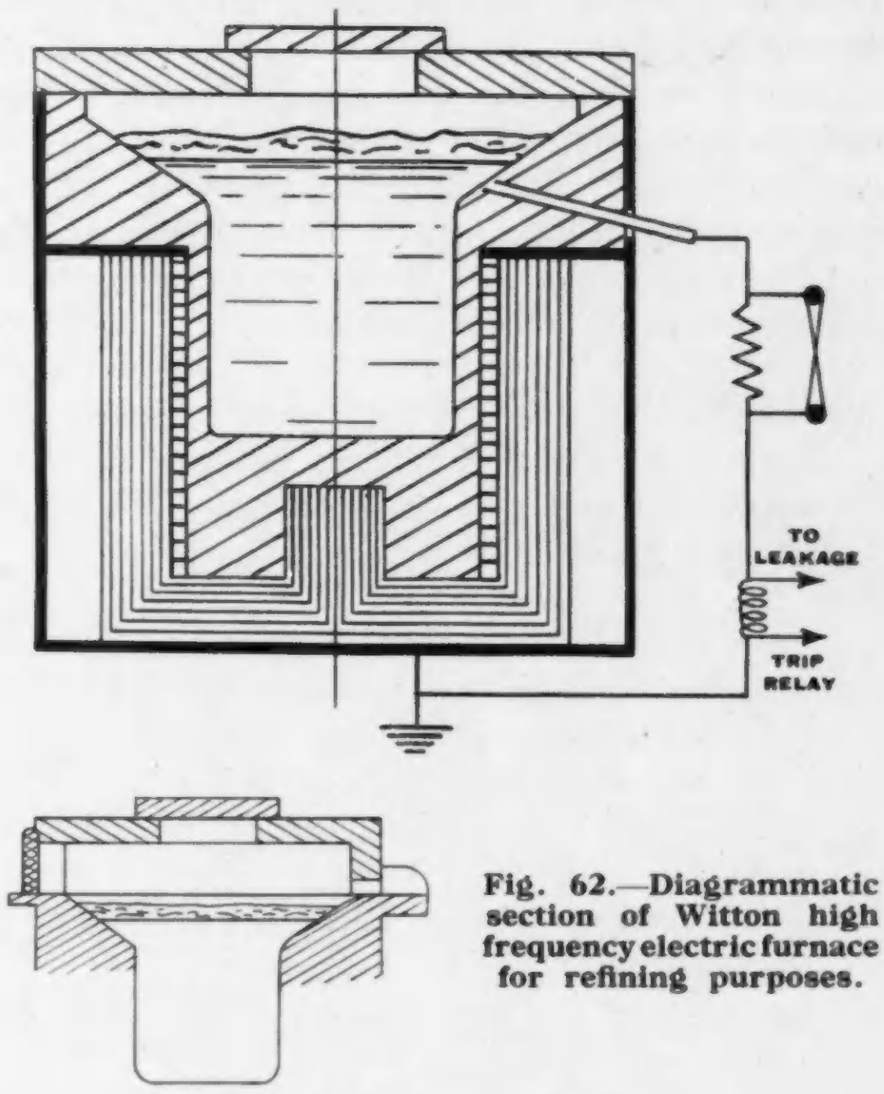


Fig. 62.—Diagrammatic section of Witton high frequency electric furnace for refining purposes.

frequency melting furnaces based on Stobie patents. Articles describing this type of furnace appeared in both Nos. 2 and 4 of Vol. III of the *G.E.C. Journal*, and obviate any present need for a general description, but the introduction of a special patented furnace construction, fig. 62, for refining purposes merits attention. The special feature of this furnace is that the crucible has a capacity of less than the volume of the charge of metal, the remainder of the charge and the slag being contained in a thick-walled funnel-shaped extension above it. Thus the slag line is on the thick sloping bank above the comparatively thin vertical walled crucible, and repairs can be made quite easily in the same way as in other types of steel refining furnaces. This construction ensures a comparatively long life of furnace crucible, as the slag is not brought into contact with the crucible proper.

Magnet furnaces have been manufactured employing the Grunewald process for the bright annealing of iron, steel, copper, etc. The process is applicable to practically all commercial metals and alloys except brass. The finish produced upon the metals is really bright, and the anneal is thoroughly uniform.

For the bright annealing of brass a special process known as the G.E.C. controlled atmosphere process has been developed in the Research Laboratories at Wembley. The methods employed have been thoroughly tested out in a large commercial furnace in Scotland, and the results have entirely confirmed those obtained in the smaller furnace available at the Laboratories.

INDUSTRIAL COOKING.

Many large installations of industrial electrical cooking equipment have been undertaken. Reference

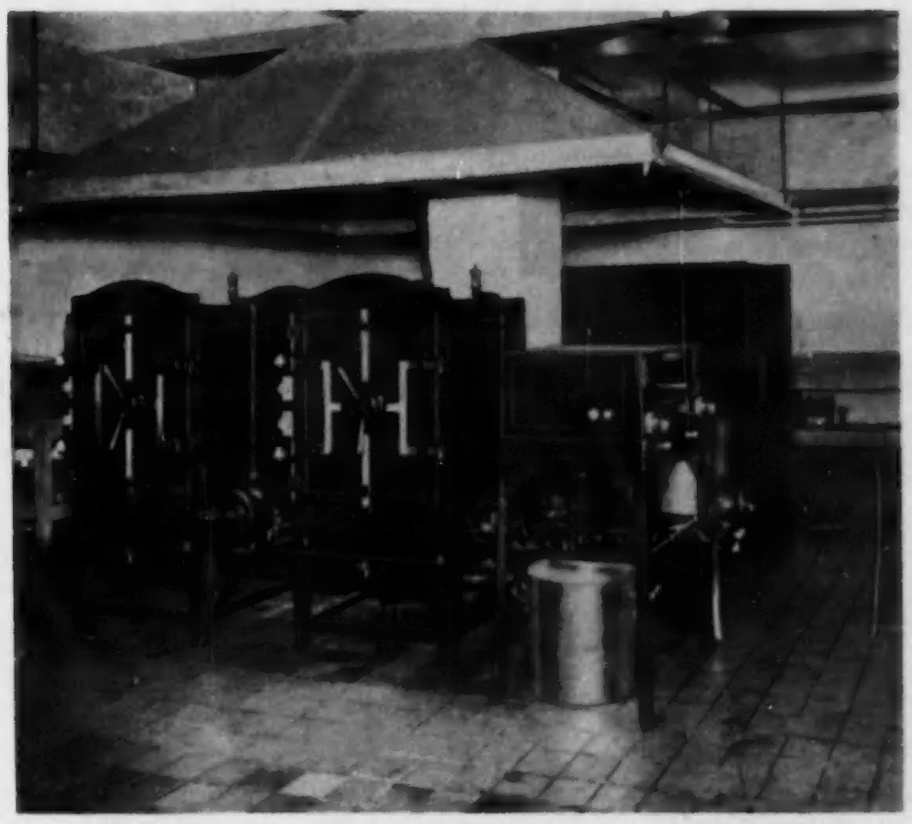


Fig. 63.—Electric cooking equipment installed in the Oxford Street Stores of F. W. Woolworth & Co.

may be permitted to one or two of the more important.

In both their large super-stores in Oxford Street, London, and their new Cafeteria Restaurant at Bristol, F. W. Woolworth & Co. have installed cooking apparatus which includes electrically heated steaming ovens, fig. 63, working under pressure, and completely self-contained. It is believed these are the only electrically heated ovens of this type in the world.

The electric cooking apparatus for the new Bank of England is of an unusually comprehensive nature, comprising three distinct equipments respectively for the main officials' kitchen, staff kitchen and vaults kitchens, also stainless steel hot cupboards, warming plates, serving tables and the like for the directors' luncheon room.

The electric cooking equipment for the Q.T.E.V. "Queen of Bermuda" is practically the same as that

for the "Monarch of Bermuda," described in *G.E.C. Journal*, Vol. III, No. 1, page 50.

IMMERSION HEATERS.

A new withdrawable embedded type of immersion heater (patent No. 369,714), has met with considerable success, as it offers advantages not possessed by earlier immersion heaters. The element consists of a pair of heating coils of nickel chromium alloy accommodated in channels in a cast iron former. The pair of coils lie in grooves, the surfaces of which are lined with refractory insulating material, and after the coils are in position the space remaining in the former is completely filled with further refractory material. The terminations of the windings are brought through porcelain bushings in a circular

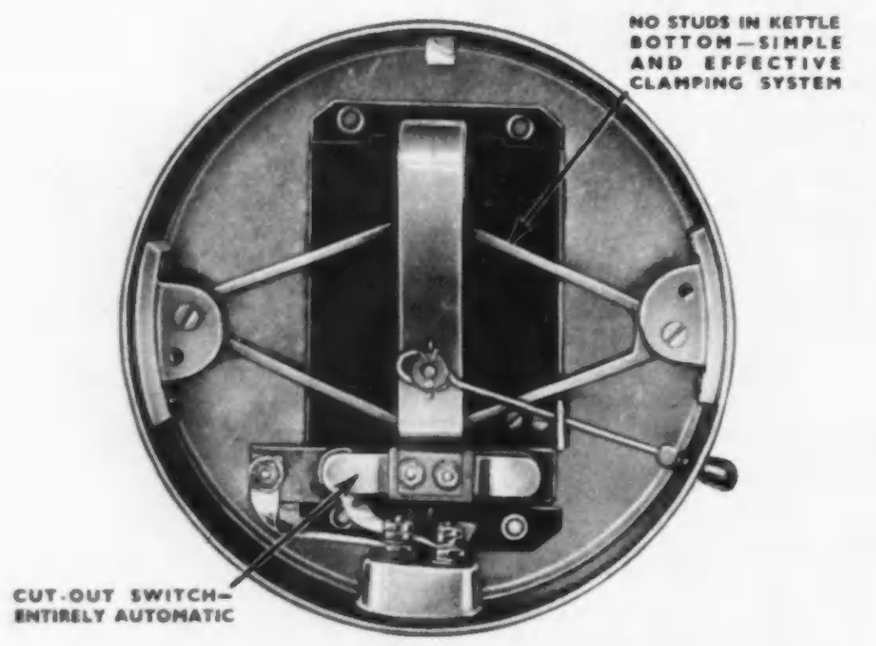


Fig. 64.—The re-set automatic safety device fitted to the new electric kettle, which protects the kettle if the latter is accidentally boiled dry.

mild steel end plate. The element is then baked to dry off moisture and harden the refractory material, after which process, a special aluminium alloy is cast around it. Finally, a glazed porcelain terminal block, carrying the usual terminal arrangements is fitted.

The heaters are arranged to fit into tubular pockets in a water-heater, the aim being to secure as good a fit between the aluminium cylinder and the wall of the tube as possible, consistent with commercial tolerances in tube bore.

This new design of heater possesses two main advantages; first, a substantially lower operating temperature which results in greatly increased life, and secondly, the great mechanical strength of the construction.

A new connector for domestic appliances has been introduced. The connector body is of moulded bakelite, and a rubber sleeve takes the place of the spring used on earlier patterns for leading the flexible into the body. This affords adequate protection to the user in the event of a breakdown in the flexible, as the rubber sleeve is easily capable of withstanding the arc formed between broken strands, or on a short circuit. The connector is fitted with floating sockets, capable of accommodating either $\frac{5}{8}$ in. or $\frac{3}{4}$ in. centre pins. The connector is also available in two patterns, one without a metal shroud, for 2-wire flexible where earthing of the appliance is not required, and one with nickel plated metal shroud and earthing contact for 3-wire flexible. An adequate cord-grip is also incorporated.

An electric bedwarmer has been designed for use in the same manner as an ordinary hot water bottle. It is connected to the electric supply for about 10 or 15 minutes, then disconnected and placed in the bed. The quantity of heat stored is about the same as for an ordinary hot water bottle of normal size.

The glazed earthenware container, which is of triangular section with rounded edges, is packed with a special heat retaining material, in the centre of which is located the heating element. This element is wound with a special resistance material, and is so arranged that whilst the heat stored in 10–15 minutes is ample for normal use, the bedwarmer will not reach an excessive temperature if inadvertently left on circuit for a long period.

DOMESTIC HEATING AND COOKING.

A great feature of the year's progress has been the remarkably extended use of Magnet hot plates. The output has been four times as great as that of 1931.

As a result of further investigations into the factors affecting casting and wire temperature, etc., it has been found possible to modify the design of these hotplates in such a way as to enable the loading to be increased. The following are the plates in question.

$8\frac{11}{16}$ in. diameter plate. Loading increased from 1,800 to 2,000 W.

8 in. diameter plate. Loading increased from 1,600 to 1,800 W.

$8\frac{1}{2}$ in. by 6 in. rectangular plate. Loading increased from 1,600 to 1,700 W.

In no case have these alterations resulted in increased wire temperature.

The Magnet storage cooker is another appliance which has figured prominently in the year's activities. Further reference to it here is unnecessary, as it was fully described and illustrated in *G.E.C. Journal*, Vol. III, No. 4, page 179.

The general policy pursued in 1932 has been drastically to reduce the number of models in the range of domestic cookers. To this end three models only are being marketed, and it is anticipated that 85 per cent of requirements will be met by two of these models which cater respectively for families up to 5 and 8 persons.

It is believed that the introduction of these two new models only, which are sufficient to cope with all the normal requirements of large and small families, is a direct measure of standardisation which

will eventually eliminate the multiplicity of cooker sizes which have hitherto been put on the market. It is considered that the current practice of many cooker manufacturers in offering an average of 10 or 12 models, which differ only in small points of design, dimension or finish, and do not materially affect the utility of the cooker, makes impossible production in large quantities of a first-class article at a low price. In concentrating upon two models only, the supply engineer will be enabled to reduce materially his stocking facilities, parts of the two cookers being made interchangeable wherever possible.

Reference was made in the last year's article upon "Progress" to new types of cookers for overseas markets. Most successful results continue to be achieved with these cookers.

A new re-set pattern kettle, in both 2 and 3 pint sizes, with loadings of 650 and 1,000 watts respectively, has been introduced, in which is incorporated a re-set automatic safety device, which protects the kettle if the latter is accidently boiled dry, or put on circuit without water. In addition, a number of improvements have been effected in the construction, including a new method of clamping the element to the kettle bottom, eliminating the holding-down studs, which were characteristic of former types. The safety device takes the form of a switch arm which is normally constrained in the closed position, by means of a trigger device. A pair of bi-metallic strips, mounted on a block attached to the kettle bottom, are arranged to deflect outwards with increasing temperature, releasing the switch arm when the temperature of the kettle bottom exceeds a safe value (fig. 64).

THERMOSTATS.

The existing range of thermostats has been increased by the addition of several new types, namely, the adjustable R.5, the R.6, the S.1, the T.1, and the air or room thermostat.

The adjustable R.5, like the R.5, is primarily intended for controlling the temperature in electric water heaters, but instead of operating only at one specified temperature, it can be set to operate at any desired temperature. The rating of this thermostat is the same as that of the ordinary R.5, namely 10 amperes D.C. or 15 amperes A.C. at 250 volts.

The R.6 thermostat is similar to the R.5, but somewhat smaller, and is intended to replace the latter for light duty. The principle of operation is exactly the same, a strip of bi-metal carrying a contact at one end, and fixed at the other to the frame, bends on the application of heat, opening the contacts. A snap action is provided by a permanent magnet, which also provides a blow-out action, enabling the thermostat to be used on D.C. circuits.

The type S.1 thermostat was developed to meet the requirements of a temperature alarm, in which the temperature sensitive element is placed in the path of an air or gas flow, and on the temperature of the latter rising above a specified amount, operates the alarm. In this thermostat, a flat helix of bi-metal strip is used, which is anchored at its inner end, the outer or free end being connected by suitable levers to a small mercury switch controlling the alarm circuit. The application of heat causes the free end of the helix to rotate, the turning movement being communicated to the mercury tube by the levers.

7 2396

Fig. 65.—A modern radio-gramophone.

For controlling the temperature of ovens, furnaces, etc., the T.1 thermostat has been developed, and this instrument is at present available for temperatures up to 600°C. It has been developed on the lines of the rod type thermostat, but with the non-expanding member of porcelain instead of the nickel steel alloy (Invar) used in the rod thermostat. The T.1 thermostat will control currents up to 10 amperes D.C., and 15 amperes A.C., at 250 volts (non-inductive circuits). The expanding member takes the form of a tube of nickel or other suitable material.

The room thermostat has been developed to meet the need for a temperature controlling device of considerable sensitiveness, for regulating the temperature of living rooms, offices, etc. It may also be used for various industrial applications, such as maintaining a constant temperature in cigar drying cabinets, etc. The thermostat is adjustable from 40°F to 130°F, and has an overlap of 3°F. It will control currents up to 15 amperes A.C. and 0.1 amperes D.C. at 250 volts (non-inductive circuits).

WIRELESS RECEIVING SETS.

In the design of the season's wireless receiving sets, points have been embodied which render them

even more simple for the user. First, all Gecophone receivers are entirely self-contained. Moreover, the number of dials has been reduced to an effective minimum by utilising a single drive to operate two or more controls simultaneously, while the reception of any required programme is made easy by the calibration of station names on an illuminated dial.

Technical improvements naturally have been linked with valve developments. The use of high conductance valves and the adoption of the screen grid detector in all receivers have led to each single stage giving a better performance. Effective use has been made of variable-mu valves and band pass filters to achieve the highest degree of selectivity compatible with really good reproduction at ample volume.

Some of the trends of design in power equipments are of importance. Electrolytic condensers have been incorporated in power and smoothing circuits for the first time, affording an extremely high capacity in a very small space at low cost. Loud speaker field windings have been employed as smoothing chokes, which effects the double economy of using the high tension supply to energise the loud speaker, and the loud speaker windings to smooth the high tension.

EMPIRE BROADCAST SCHEME.

The inauguration of the Empire Broadcast Scheme has created a rapidly increasing demand for short wave apparatus from overseas. For this purpose an A.C. mains superheterodyne receiver (overseas model) has been developed, which is capable of very long distance reception over the whole of the short wave-band used for these transmissions, in addition to covering the medium wave-band from 200/550 metres.

As an allied line of some moment, there has been designed and manufactured conversion equipment suitable for the operation of D.C. mains apparatus after a supply system has been changed to alternating current. This equipment should prove of value owing to the large number of areas which have recently changed over both in this country and abroad.

As far as sound reproducing equipment is concerned, an entirely new range of apparatus is available, far too comprehensive to be outlined in the space here available, but reference should be made to a power amplifier of only two stages, capable of working direct from a carbon microphone and having an output of 6½ watts (A.C.). It gives straight line amplification between 50/8,000 cycles. Complete installations suitable for hospital or radio relays have also been designed, and the range of this class of equipment for indoor or outdoor use covers all reasonable requirements.

PHOTOELECTRIC CELL EQUIPMENT.

Great strides have been made in the development of photoelectric cells and their application to industry. One of the most interesting is their use in talking film equipments. Several alternative types of the caesium-on-silver cells have been produced for this purpose. Other applications for which equipment has been designed include television apparatus, newspaper telegraphic instruments, detection of atmospheric impurity, the control of lighting signs, the timing of greyhound races, the protection of papermaking machinery in the event of breakages of the paper, also the counting of motor tyres, steel tubes, packages of various kinds, etc. The applications of the photoelectric cell are so numerous and of so diverse a character that it would be quite impossible to convey in an article like the present any idea of the apparatus involved and its many-sided functions; but the following brief detail of an equipment recently installed in Stewart & Lloyds tube works is typical of possibilities.

The process of manufacturing welded steel tubes requires very rapid handling of the hot steel strip from which these tubes are rolled, right from the moment when the heated strip is pulled out of the furnace with a temperature of over 1,350°C to the end of the process when the finished tube moves down the cooling rack at the other end of the tube mill plant.

Tubes of this description are usually from 15 ft. to 18 ft. in length, and the time interval between the rolling of the tubes in the most up to date process is a matter of a few seconds. The tubes, after they have passed through the sizing rolls, run at a considerable speed down a trough, and are auto-

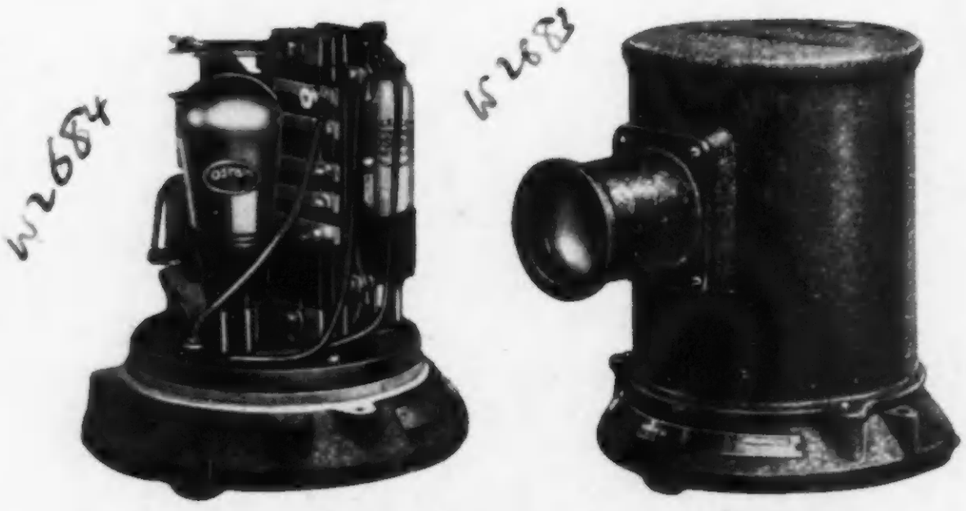


Fig. 66.—Internal and external views of photocell and amplifier.

matically transported to the cross rolls for hot straightening. After they have passed the cross rolls they move on to a cooling bank, dropping into a collecting cradle, whence they are taken away in bundles by means of overhead transporters to the finishing shops for cutting into lengths, testing, screwing, etc., before going into the warehouse for despatch.

Owing to the rapidity with which the tubes

follow one another through the sizing rolls and the cross rolls, the operation of releasing them from the cross rolls to the cooling bank is one which demands constant watchfulness and prompt action on the part of the operator. This will be realised from the fact that the distance between the tail end of one tube and the nose of the next following tube is often only about three feet. The slightest error in timing by the operator will result in a temporary stoppage due to collision between the tubes. Mechanical means to check these operations and to prevent the tubes from colliding or being sent forward into the cross rolls before the preceding tube had been cleared have failed. The reason for the failure was that any lever or electrical appliance that was struck by the hot tubes travelling at a great speed in rapid succession was damaged by the impact within a very short period of time.

The whole matter was therefore investigated by the G.E.C. with a view to developing photocell equipment for carrying out these operations efficiently. It was found that the radiation given out by these hot tubes will operate a photoelectric cell placed within a few feet of the tubes as they travel from the sizing rolls through the cross rolls to the cooling bank. The current set up in the photocell is amplified by an Osram valve, and relays operate an electrical contactor, which closes the circuit of a powerful solenoid. By means of the solenoid, the releasing shutters, which were originally operated by hand, are automatically operated at exactly the right moment, and by this means collisions of tubes, etc., are prevented.

Fig. 67.—Photocell equipment installed at Stewart & Lloyds tube mills.

At the same time each tube is counted in a similar way by means of its radiation being picked up by another photocell equipment which operates a solenoid operated counter. Further, optical warning signals, consisting of red and green lights, are installed to indicate to the men at the furnaces and the racks when the line is safe for sending along another tube, or when the passage is blocked.

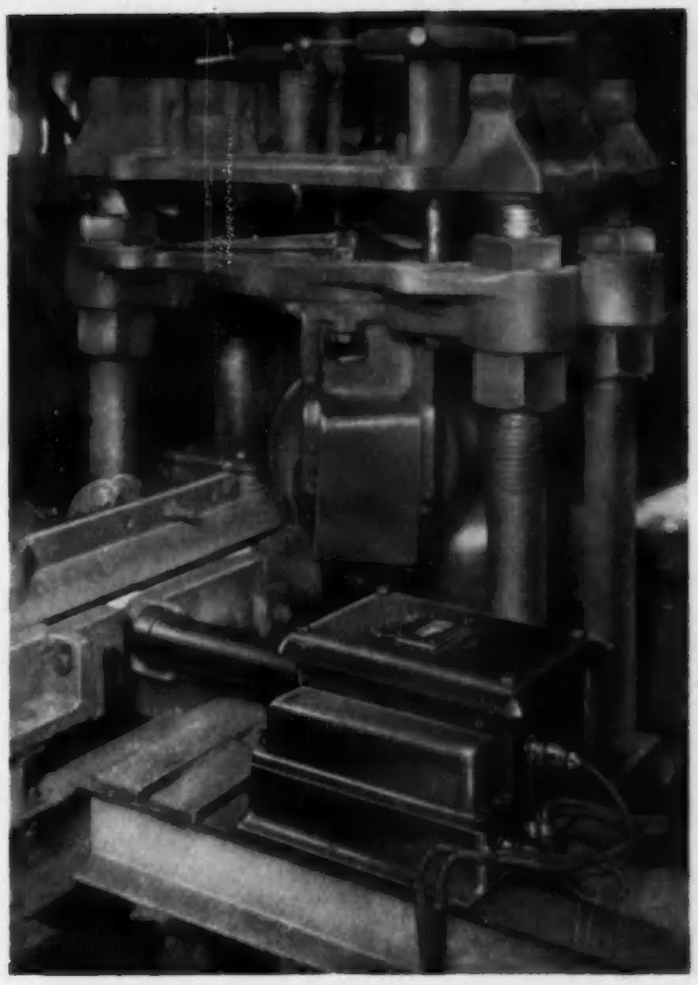


Fig. 68.—Detail view of photocell equipment seen in fig. 67.

Provision can also be made, when desired, to test the actual temperature of the hot strips when leaving the furnace, or of the tube at any time of its travel, by means of photoelectric temperature recorders.

INSTRUMENTS AND TESTING SETS.

The principal results achieved in connection with electrical instruments have led to improved construction and greater efficiency; further, existing types have been applied to a wider range of purposes.

Employing the well known fact that the resistance of a column of liquid varies with its purity, an instrument has been developed to indicate purity of liquids; the purity of water is frequently tested in this way. Across a supply of known voltage is placed a millammeter, moving coil for D.C. supplies, and a rectifier and moving coil instrument combination for A.C. supplies, in series with two electrodes, which are a specified distance apart in the liquid under test. With a pure liquid an indication is obtained which varies as the purity decreases. To protect the instrument against damage due to complete failure of the resistance of the

liquid, two small lamps are also inserted in series with the electrodes.

A small rectifier attachment incorporating a metal oxide rectifying unit has been developed, by which the range of usefulness of the well known No. 4 G.P.O. Detector can be increased. By the addition of this unit readings can be taken up to 15 m.a. and 150 or 300 volts A.C.

Another new device consists of an ohm-meter employing thermionic valves for testing insulation resistance values at 500 and 1,000 volts D.C., giving indications direct in ohms on a calibrated scale. The source of supply is 230 volts A.C., and the valves employed to give full wave rectification are one Osram U.14 and two Osram GU.1 valves for the 500 and 1,000 volts tests respectively. A push switch is arranged to change over from one voltage

Fig. 69.—"Salford" valve testing equipment.

to the other. A portable pattern has also been manufactured, but the test voltage is 500 volts D.C.

For testing thermionic valves, both rectifying and radio receiving types, a test set has been designed which is so arranged that any type of valve at present on the market can be tested with the minimum amount of labour, the operator merely having to change switching positions (fig. 69).

ELECTRICITY METERS.

An important addition to the Chamberlain & Hookham range of meters is an alternating current meter for single phase circuits (fig. 70). It possesses the advantages of small size and light weight, yet gives an improved performance in comparison with earlier types. Its losses are very low. It has the present day long range of load characteristic. The adjustments are very simple, and, being provided with indicators, the work of recalibration in meter test rooms is rendered very much simpler than heretofore.

The increasing introduction of two-part tariffs by electricity supply authorities has created a demand for a suitable meter for dealing with prepayment consumers in those areas where this class of tariff is applied. In consequence there has been developed a two-part tariff prepayment meter (fig. 71), which

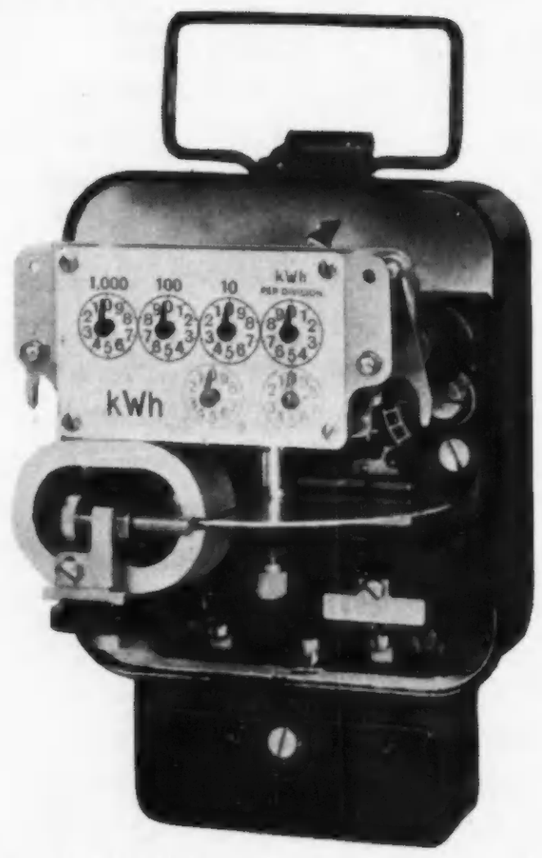


Fig. 70.—Chamberlain & Hookham A.C. meter for single phase circuits.

is entirely suitable for such consumers. It consists of an addition to the standard prepayment mechanism, whereby a standing charge of any desired amount within limits may be collected. The whole of the apparatus is housed in a case uniform in size with the standard prepayment meter. The addition comprises a dial reading to 20 shillings or alternatively 40 shillings, and an adjust-

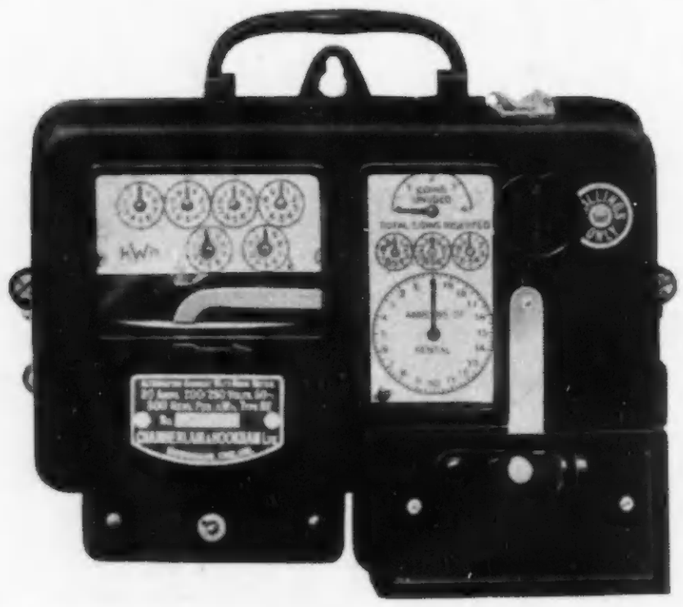


Fig. 71.—Chamberlain & Hookham two-part tariff meter.

able index whereby the amount of standing charge to be collected from the consumer during the succeeding collecting period may be set. The setting of the index is performed by the meter reader, who inserts a key through the meter cover and turns the index into the appropriate position. This operation can only be accomplished when the

coin drawer is removed; at other times the key-hole is inaccessible.

The meter functions in the following manner. The standing charge is set by inserting a key through

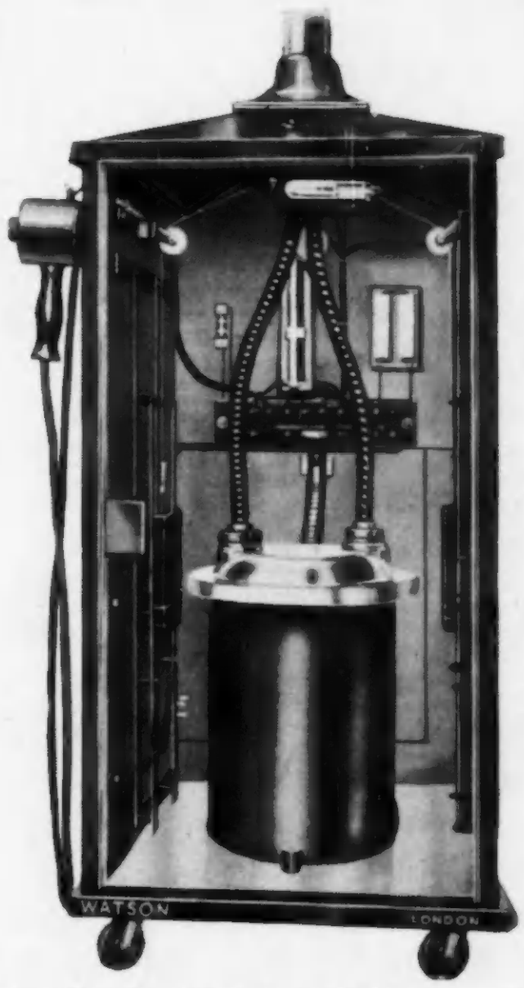


Fig. 72.—Shockproof dental X-ray equipment.

a hole situated behind the metal strip below the coin operating handle. Each time the consumer inserts a shilling, a portion of its value is allocated by the mechanism towards the cancellation of the standing charge, and the balance provides for a limited supply of current. The amount allocated to standing

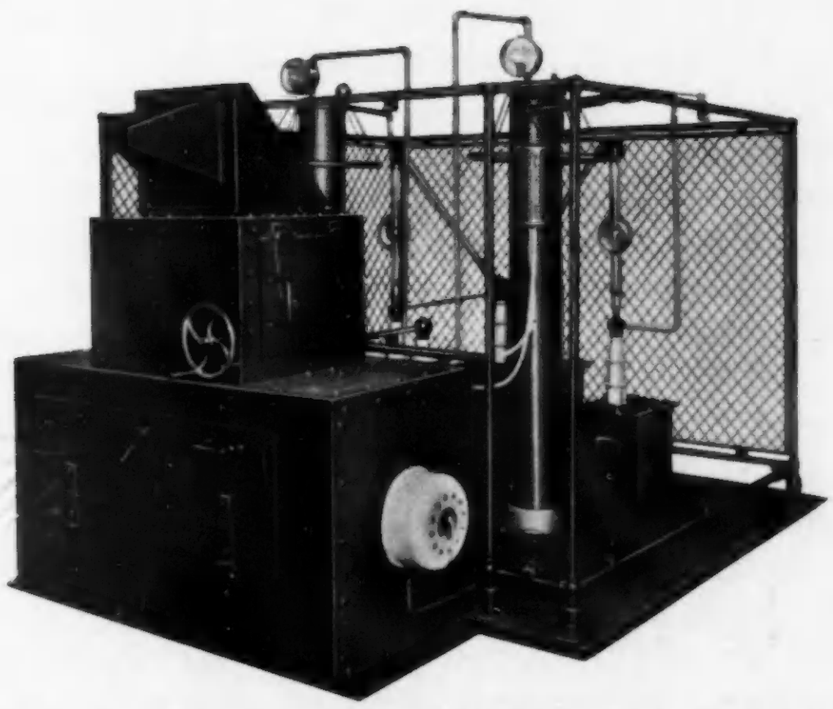


Fig. 73.—X-ray equipment for examination of steel specimens.

charge is deduced from the reading on the standing charge dial, the index of which shows the arrears outstanding. The balance of each coin inserted advances the "coins unused" index a suitable amount, and this in turn travels back towards zero as current is used.

In due course, after a sufficient number of coins have passed into the meter, the standing charge index will reach zero point, indicating that the whole of the standing charge for the particular accounting period has been paid. From this point onwards, the whole of each coin inserted will be allocated to providing current at the low price per kWh, and since no reduction is made for standing charge, the consumer will now have the benefit of an increased supply of current for each coin. This state of affairs will continue until the collector calls to empty the cash box, on which occasion he will set the standing charge index to the appropriate position for the ensuing quarter.

Special provision is made for cases where an

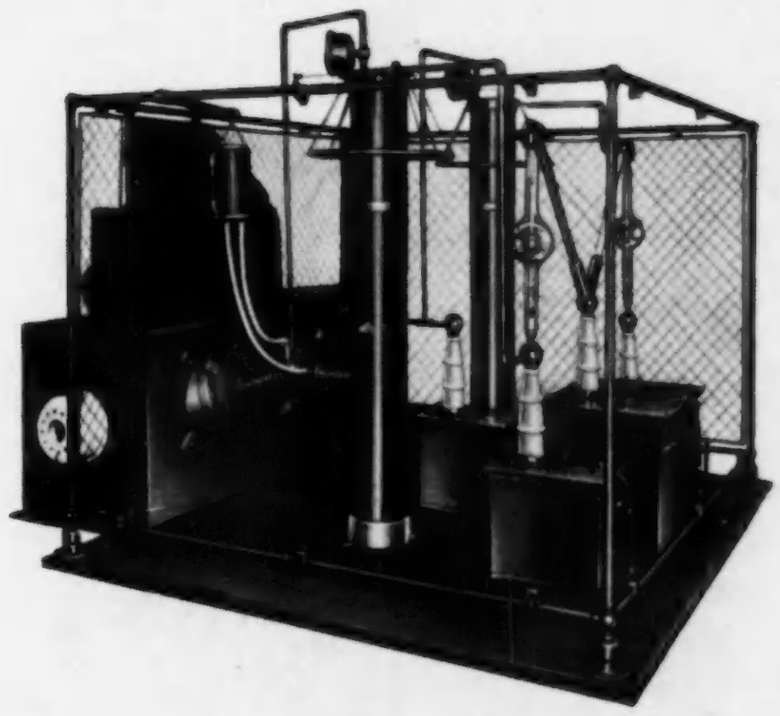


Fig. 74.—Another view of the equipment shown in fig. 73.

unusually small quantity of current may be used. Suitable adjustments provide for variation in the price of current.

A portable testing set for testing polyphase meters on site fills a long felt want. It has been common practice in the past, when carrying out tests on site, to connect a check meter in series with the meter to be checked, leave the two running for several days, and then compare the readings of the two meters. This method does not give unqualified satisfaction, and in general the comparison only shows the average errors over a period without giving any indication of the errors at specified loads.

It usually happens that the load is not under the control of the testing engineer, more particularly if the test is being carried out in a generating station or a large industrial undertaking. The alternative to this method has been to remove the meter to the test room, and there carry out tests over the whole range of measurement and at various power factors. The objections to this alternative are that when the meter is disturbed an existing error may disappear or be modified, or conversely the disturbance may actually introduce an error. In any case, there is no

guarantee that the conditions of working on site will be reproduced in the testroom.

The portable polyphase meter testing set has therefore been designed with a view to removing these objections and enabling a complete series of tests to be carried out on site at any desired load and over a sufficient range of power factor to satisfy all practical requirements.

X-RAY APPARATUS.

During the year the development of X-ray apparatus carried out by Watson & Sons (Electro-Medical) Ltd., has been in two main directions, one being the development of shockproof diagnostic

Fig. 75.—Crystallographic apparatus for examination of materials.

equipment and the other industrial equipment, both for radiometallography and crystallography.

An example of shockproof diagnostic apparatus is the Dental X-ray unit (fig. 72). The X-ray tube is enclosed in a small metal housing, the high tension being fed to the tube by flexible cable covered with an earthed metallic sheath.

The cabinet houses a small transformer capable of an output of 10 milliamperes at 45,000 volts R.M.S. The high tension cables are plugged into the top of this transformer, which is provided with a metal cover. A safety switch is fitted to the door.

New shockproof equipment for higher voltages is being developed, and a compact shockproof X-ray equipment is shortly being introduced, suitable for industrial radiography or medical deep therapy treatment, capable of giving 4 milliamperes at 200,000 volts.

Recent industrial apparatus manufactured includes an equipment supplied to U.S.S.R. (figs. 73 and 74). It consists of a high voltage constant potential generator capable of an output of 10 milliamperes at 200 kV direct current, together with a special X-ray tube box arranged for the examination of steel specimens by either direct visual observation or by radiography.

A recent development is a crystallographic apparatus arranged for examination of materials by the methods of either Laue or Debye-Shearer, or the powder method of Hull. The apparatus consists of a constant potential generator having an output of 30 milliamperes at 60 kilovolts direct current, together with a special research X-ray tube and turret containing the tube, which can be adapted for whichever method of analysis is preferred. An advantage of the equipment is that eight specimens can be examined simultaneously. The turret and cameras arranged for examination by the Laue method are shown in fig. 75.

In electro-medical work the main development has been the production of a valve diathermy apparatus for surgical work. This equipment is known as the "Chirotherm."

This is the only surgical diathermy apparatus of its kind made in this country, and possesses the unique distinction that with it, not only can coagulation be carried out, but fat, tissue and skin can be cut with great rapidity, and the healing is not marred by ill effects. Furthermore, the formerly serious objection of muscular contraction has in this machine been overcome.

BATTERIES.

A new dry cell of the paper lined pattern has been introduced. It is designed for tropical and hot climates, and where a high short circuit test current of the order of 40 amps or more is desired. The thinness of the paper lining, compared with the greater thickness of the more usual paste electrolyte, ensures that the maximum possible quantity of depolarising material is available. The paper is so treated that it is kept moist and saturated with electrolyte, so that drying up is completely eliminated. This cell possesses a long shelf-life and a very low internal resistance; it will give also a long life on an intermittent service.

MINING APPARATUS.

Several new patterns of mine-signalling apparatus, which meet with the approval of the Mines Department, have been developed. These include a new form of relay which is already installed in several mines, also a new mining magneto ringing telephone and a battery ringing mining telephone.

For shot firing in gaseous mines a new mine exploder is available. It is, in effect, a magneto electric machine, which is made in two designs, for

either high tension or low tension circuits. The device complies in every way with the latest mining regulations.

LUMINOUS SERVICE INDICATION.

The Magnet system of luminous service indication is the subject of continual improvement. The inconvenience of audible signals is well known, and even when the calls are recorded visually there are obvious limitations to effectiveness. The latest installations of the system provide indicating lamps, not only at the serving but at other suitable situations. Further, a visible record is given to the caller, showing that the signal is operating. The new features thus incorporated in the system are made possible by a new relay switch. The visible indication remains, even though the push circuits are open, until a lamp cap upon the relay is pressed.

ELECTRIC TORCHES.

The popularity achieved by the standard bakelite torch has led to the introduction of a focussing spotlight bakelite torch, which has an adjustable lamp to project a spot beam or general light as required. It is of interest that this torch has successfully withstood tropical conditions. In addition a miniature bakelite torch suitable for carrying in the pocket or in a lady's handbag has recently made its appearance.

ELECTRIC LIGHTING SWITCH AND FUSE GEAR.

The "Minor" fuseboard is an entirely new production for use on lighting circuits, and complies fully with Home Office requirements. The range available covers from two to ten double pole branch circuits. The board is contained either in a teak or a pressed steel case. The latter is finished in silverlac, a finish which is standard on G.E.C. lighting fuse boards, and presents an altogether better appearance than is usual with painted iron; moreover it offers a more lasting surface.

Two additions have been made to the range of switch-plugs. The first is a bakelite D.P. face entry 3-pin tumbler switch-plug, available in 5 and 15 ampere sizes, which combines the "Landor" quick make quick break switch movement with a 3-pin British Standard gauge face entry socket. The second addition is a D.P. 3-pin interlocked switch-plug, made in surface semi-recessed and flush patterns. It also incorporates the "Landor" quick make quick break switch movement and 3-pin British Standard gauge socket.

A novel form of lampholder for use in a new series lighting system for tram and train illumination consists of an Edison screw holder, in which the lamp cap operates a spring contact, which is arranged so that when the lamp is removed the holder is automatically short circuited, thus keeping the remainder of the series alight. It will be readily visualised that a lampholder of this kind has many applications apart from the particular system referred to.

A further step in the direction of safety has been made by the production of an Edison screw holder in which the thread has been moulded into the porcelain body. In this way, the copper shell, which is always a potential source of danger, has been eliminated, and contact is not fully made until the lamp is in position.

An intermediate pattern of the "Landor" quick make and quick break switch is available.

A safety shield has been developed for fitting to the range of "Landor" switches. This consists of a bakelite supplementary shield which can be locked in position underneath the ordinary cover over the terminals of the switch, so that if the outer cover should be removed no live metal is accessible.

The increasing popularity of bakelite for use in the manufacture of wall plugs is further exemplified in the production of two new lines of all-bakelite flush socket and plugs. These are being made 5 amp. 3-pin and 15 amp. 2-pin, and are designed for fixing in conduit boxes or direct to the skirting board.

MOULDED PRODUCTS.

Reference has been made in earlier sections of this article to the uses of bakelite in the construction of various classes of apparatus. It should not be overlooked that this material, together with many other moulded products, is made in a works at Witton which is specially reserved for moulded insulation. During the year this works has again been extended. One section of the extension is of particular interest, as it caters for the production of cabinets for the wireless sets manufactured at the G.E.C. Telephone Works and by other wireless manufacturers. Some of the types of cabinet represent the largest mouldings ever produced in this country, and involved the installation of bakelite presses which are the largest British presses yet produced for bakelite moulding work.

Luminous Discharge Tube Lighting.

By CLIFFORD C. PATERSON, O.B.E., M.Inst.C.E., M.I.E.E.

Director of The Research Laboratories of The General Electric Co., Ltd., Wembley, England.

The article which follows reproduces in substance a lecture delivered by the author before the Illuminating Engineering Society at the Wembley Research Laboratories of the G.E.C. An account is given of the general principles underlying the working of discharge tubes, both of the older high-voltage type, and also the newer hot-cathode tubes which operate at ordinary lighting-mains voltages. The latest developments in the direction of practical lighting units of the latter kind are described.

Acknowledgment is made to the "Illuminating Engineer" for permission to reprint the article and to reproduce certain of the illustrations.

INTRODUCTION.

IT may be stated with confidence that the luminous discharge tube is to play a big rôle in electric lighting of the future. One bases this opinion more upon a broader survey of the physics of the subject than upon what has already been achieved in decorative and display lighting, noteworthy as this undoubtedly is. Whilst one cannot at present point with any certainty to a given combination of the many and complicated phenomena which are embraced by the term luminous discharge, and predict that this or that will be the line of big industrial advances — one can, without hesitation, say that the limits to progress set by theoretical considerations are, in the case of the discharge tube, far wider than physical laws permit in the case of the incandescent filament lamp. Perhaps this is particularly so when we consider efficiency. A light efficiency of many times that of the filament lamp is already certain. In colour the discharge lamp has a wide flexibility, although we cannot yet always achieve exactly what we want in reproducing the conditions which daylight imposes upon us. In geometrical form we shall have a much wider choice than the filament lamp can ever give. On the score of electrical simplicity nature has not been so kind to the gas discharge lamp. It is here probably that the filament lamp will ultimately have its chief bargaining point. But we must not lose our perspective. When in 1878, Swan first produced his electric lamp with its carbon filament about $\frac{1}{32}$ inch diameter, and 1 inch long, if as much had been known about gas discharge tubes as we know to-day, what would have been the views of the experts on the question of which system would yield the most commercial 230 volt lamp? Would anyone have believed that a filament of the size of the thread of a spider's web could have been made to glow for 1,000 hours at a temperature of 2,700 degrees with no more than 1 per cent of failures before 500 hours? Would not everyone have pointed to the gas discharge lamp as the only promising avenue for electric lighting? It is true that the discharge lamp is to-day further advanced than the filament lamp was in Swan's day, but one must admit that to-day there is probably as much

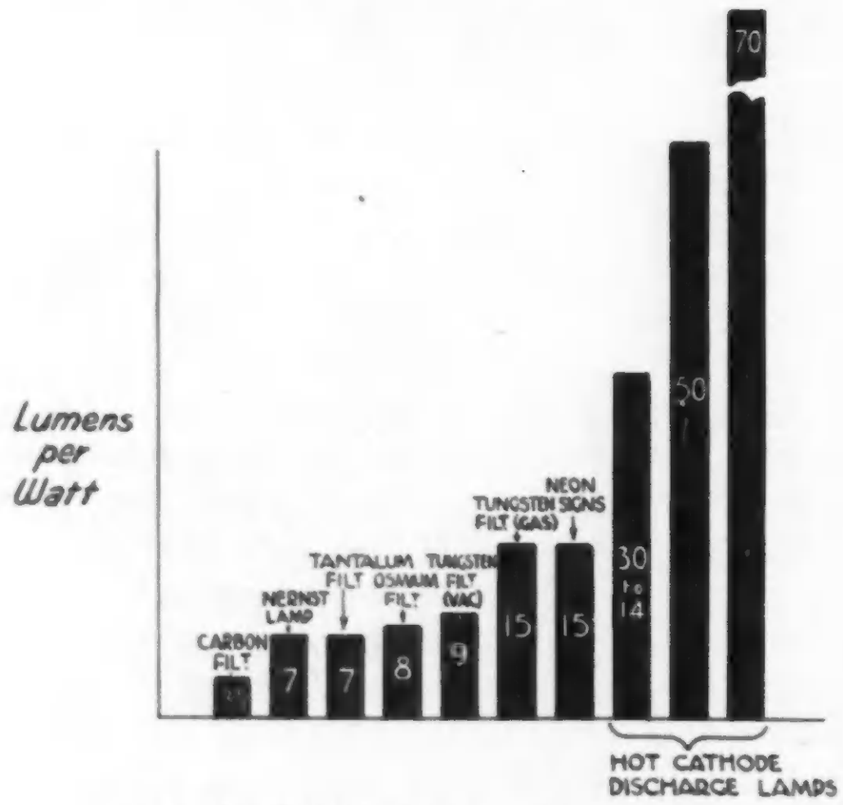


Fig. 1.—Efficiency of various lamps.

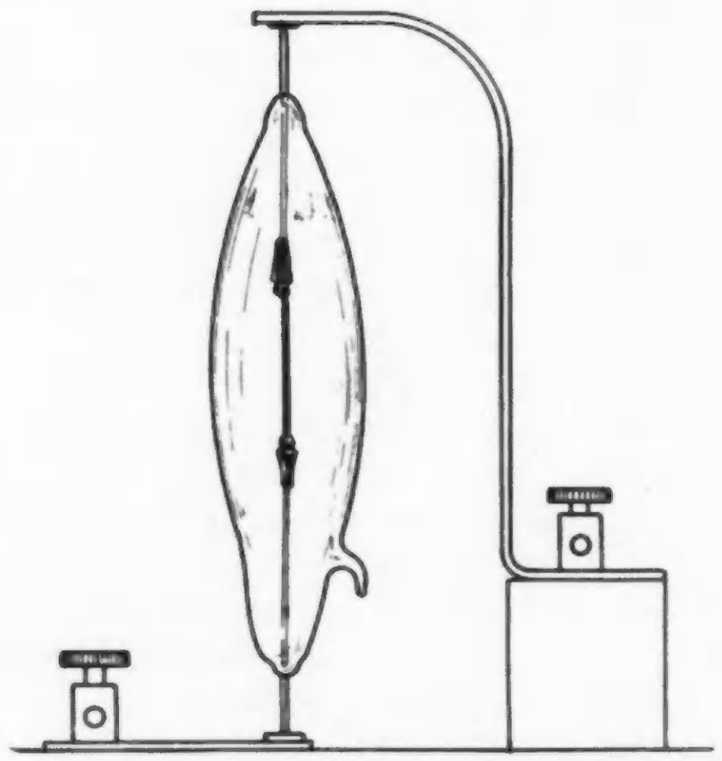


Fig. 2.—Swan's first incandescent lamp, 1878.

to find out in the theory and possibilities of the gas discharge lamp as in 1878 there was to discover in the filament lamp.

This is not predicting the early or even the ultimate substitution on a large scale of the present filament lamp by discharge lamps. The filament lamp is too simple and effective a product of engineering and scientific skill to be thus displaced. But the discharge lamp is certainly going to evolve its own field of usefulness and weave itself into our picture of electric lighting of the future.

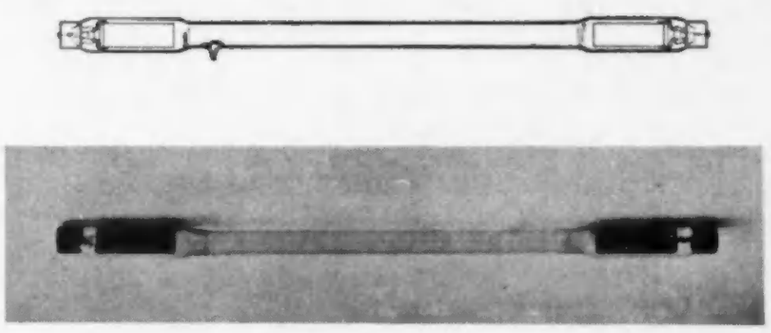


Fig. 3.—Simple form of gas discharge tube.

The object of this lecture is to explain those features and characteristics of discharge lamps which the engineer needs to grasp if he is to have the same intelligent appreciation of the way they function as he now has in the case of the filament lamp. No one who speaks to electrical engineers in these days needs to apologise for assuming a general knowledge of atomic physics. That has become as much a part of our intellectual stock-in-trade as Ohm's law was to the engineer of twenty years ago. Let us bear in mind, however, that there are still many engineers with us who learnt their engineering in Ohm's law days. Will any latter day engineers therefore overlook what will sometimes be an assumption in what follows

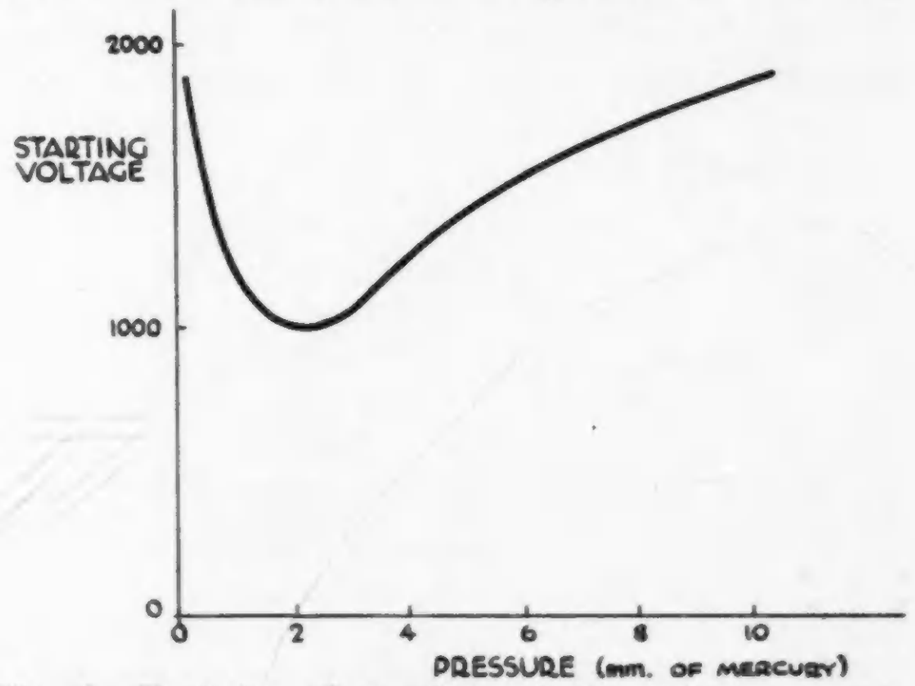


Fig. 4.—Variation of starting voltage with pressure in cold cathode neon tube.

of too little knowledge of the atom and its manner of emitting electro-magnetic radiation.

WHY DOES A TUBE RADIATE LIGHT?

We had better be clear first of all about what is meant by a gas discharge tube. For present purposes is meant a tube with transparent walls in which are two electrodes, one at each end, across which the voltage is applied. The gas in the tube is carefully controlled as to quantity and purity so that it radiates light as we want it to, under the influence of the current which passes through it from one electrode to the other.

In fig. 3 is such a tube. It is an example of the type used extensively for advertising signs. The first thing of course to notice is that, unlike an incandescent lamp, it has nothing visible connecting the two electrodes inside the tube. How then is current to pass and light to be radiated? The superficial answer is that the tube is filled with a gas at low pressure; it is this which both conducts the current and gives off the light. But it is vital to our intelligent understanding of the subject of discharge tubes that we should have a picture in our minds of the manner in which the gas does this. It will not, however, be possible to do more than give a very brief outline of this fascinating but most complicated process.

Except in extra high tension work, we are accustomed to think of the air as an insulator. Imagine the difficulties which we should encounter if it were even a moderate conductor at ordinary supply voltages. Refined measurements do, however, show that the air and other gases are not perfect insulators. An extraordinarily minute current does indeed flow between two electrodes in air even when the voltage is quite low. This current is, however, so small that it would need to be enormously magnified before it would be measurable

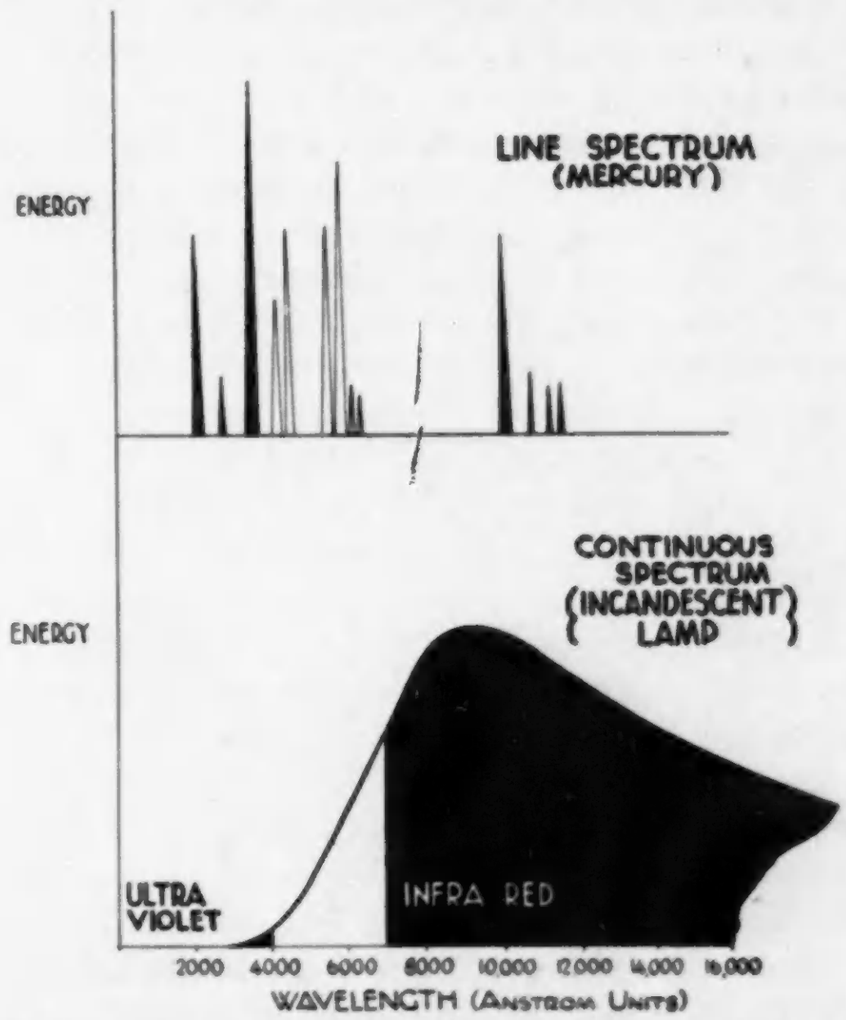


Fig. 5.—Energy distribution in continuous and line spectra (not to same scale).

on a sensitive galvanometer. Although utterly negligible in most work, it must not be thought to be unimportant. As a matter of fact, it was owing to the careful study of this minute conductivity of the air that the penetrating radiation from outer space, now known as the Cosmic rays, was discovered.

We have good reason to believe that if a gas could be completely shielded from this and other radiation or sources of ions, it would be strictly a

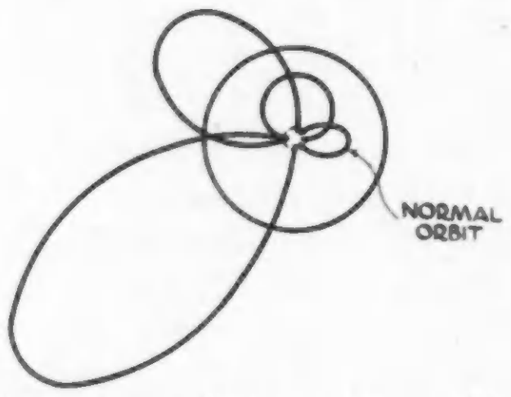


Fig. 6.—Sodium atom : diagram of possible orbits of the valency electron.

perfect insulator. Actually, however, these Cosmic rays and other ionising agents produce about 100 ions per second in the 400 million million million molecules of gas present in every cubic inch of the air around us and also, of course, of the gas in our tube. If a small potential difference is applied to the electrodes these primary ions travel through the gas and constitute a very minute current. When the voltage is increased, a time comes when some of the ions in colliding with the gas atoms will produce other ions and these again still more. The number of ions thus rapidly increases at compound interest until the flow is so great that it constitutes an appreciable current. Our insulating gas has thus in effect become highly conducting. It is of interest, however, to realise that without these primary ions in the gas to start with, it would refuse to react to the voltages we apply to our tubes and there would be nothing to start up the complicated train of phenomena we are about to consider. We must not, however, suppose that the gas will behave as an ordinary metal conductor would do. We shall find that it does not obey Ohm's law and that it also behaves in other peculiar ways, some of which we shall touch on later. Before leaving the question of how the discharge starts and the gas becomes conducting, there is one further point to be cleared up. Why must the gas be at a low pressure?

If the gas in our tube were at atmospheric pressure, we should have to apply a potential of many hundred thousand volts before the discharge would start, and when it did, it would take the unwanted form of a spark. As we decrease the gas pressure, we find that the necessary starting voltage becomes considerably reduced. This is because the gas atoms are farther apart and the primary ions can thus gather more speed before collisions. At very low pressures, however, you will see that the voltage needed will rise again, since there are then comparatively few atoms present, so that the chance of ionisation becomes very small. The starting voltage of our gas discharge tube will thus be a minimum at a certain pressure which, in the case of neon gas, is of the order of a few millimetres of mercury. One other important point is that the visible form of the discharge changes as the pressure is reduced and instead of a spark we find that the tube becomes filled with a luminous glow.

Now for the second question. How is this light produced? A wire through which a current is passing does not emit light unless it is being heated by the current to a high temperature. Then the light emitted is just the same as if the wire had been heated to the same temperature by a flame instead of by a current. When analysed by a spectroscope the radiation will be found to be "continuous," that is, a certain amount of each wavelength will be found in it. The radiation from a luminous discharge in a gas or vapour is, in general, quite different from this. On analysis, only certain wavelengths, all highly characteristic of the gas, are found to be present.

A normal atom of a gas consists of a central positively charged nucleus round which negatively charged electrons revolve in certain orbits. Now suppose an electron or ion to be moving under the influence of the voltage gradient along our tube. We have seen that, as it moves, it is continually colliding with the gas atoms; actually a collision will take place about every tenth of a millimetre of its path when the gas is at the low pressure we are considering. So long as the velocity is small, which the ion has gathered in its fall through the voltage gradient along its track, it will rebound at each

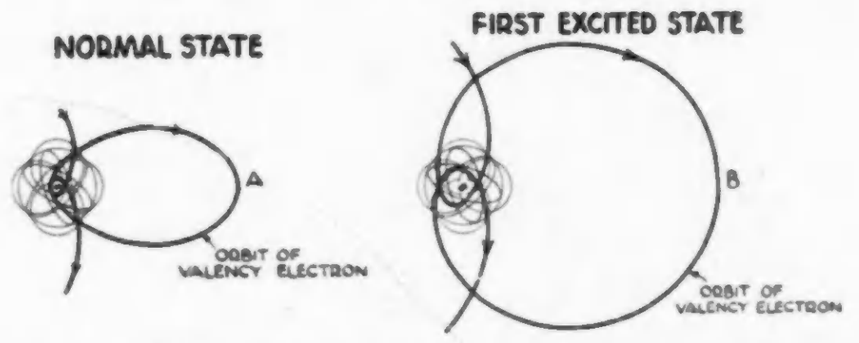


Fig. 7.—Sodium atom : an electron transition from orbit B to orbit A leads to the emission of the yellow sodium line 5890 A.U.

collision just as if the atom and ion were perfectly elastic billiard balls; their combined energy of motion will be the same after as before the collision. But as the voltage between the ends of the tube is increased, the velocity, and therefore the energy which the ion acquires in its fall, will also increase, and when this becomes greater than a certain critical value, an extraordinary thing happens. The whole of this critical amount of energy is used up in transferring one of the electrons revolving round the atom

to an exterior orbit not normally occupied by an electron. Any excess of energy over the critical amount needed for this, shows itself as kinetic energy of motion divided between the two bodies. The atom with its electron in an outer orbit is said to be in an excited state. However, it generally does not long remain in this abnormal condition; the outer electron soon returns to its normal orbit and in doing this the important thing happens. The energy which was absorbed in changing the orbit is now ejected as radiation. The additive effect of thousands of millions of atoms all behaving in similar ways gives us the radiation we observe from the tube. Radiation of what wavelength? The answer to this involves one of the most fundamental laws of modern physics. This remarkable relation, which to the physicist of to-day is what Ohm's law has been to the electrical engineer, states that the frequency of the radiation emitted is proportional to the energy emitted by the atom during the process of radiation.

Energy (E) = Planck's constant (h) × Radiation frequency (ν).

Since a short wavelength corresponds to a high frequency and *vice versa*, we see that the higher the energy of an atom in the excited state, the shorter the wavelength of the radiation emitted when the electron returns to its normal orbit.

Now although we have only considered one critical energy value of excitation, all atoms have a vast number of such values corresponding to transitions of electrons to different orbits. Each kind of atom has its own characteristic set, and, when recovering from the excitation by ionic collisions, emits radiations having a corresponding set of wavelengths.

If the energy of the colliding ion is gradually increased, a point will be reached when it has so much energy that, instead of transferring an electron in the atom to an extreme outside orbit, it succeeds in completely expelling the electron. The collision then results in the formation of two new ions, the atom, now positively charged (since it has lost an electron), and the free negatively charged electron which has been ejected from it. When this happens the atom is said to have been ionised. If this ionisation has taken place in an electric field, these new ions dart down the voltage gradient and proceed to generate others, and these again still more by compound interest, thus initiating the discharge in the manner already described.

Before leaving the theoretical aspects of the discharge processes let us illustrate them by an example. Suppose our tube to contain sodium vapour at a low pressure. The critical energies and corresponding wavelengths for sodium are given in the following table. The energies are given in terms of the voltage difference, through which an electron must fall in order to acquire the corresponding energy. This gives a convenient energy unit known as the electron-volt.

Critical energy in electron-volts.	Corresponding approximate wave-lengths.	Type of radiation emitted.
2.1	5,890 A.U.	Yellow (D)
3.2	11,400 ,,	Infra red
3.6	8,190 ,,	Infra red
4.1	6,160 ,,	Red
4.3	5,685 ,,	Green
.	.	.
.	.	.
.	.	.
5.12	Ionisation	

If electrons are flowing through the vapour in circumstances such that they can never acquire an energy of more than 2.1 electron-volts (the first critical energy value) no light is emitted. But if we apply a potential sufficient to start a discharge

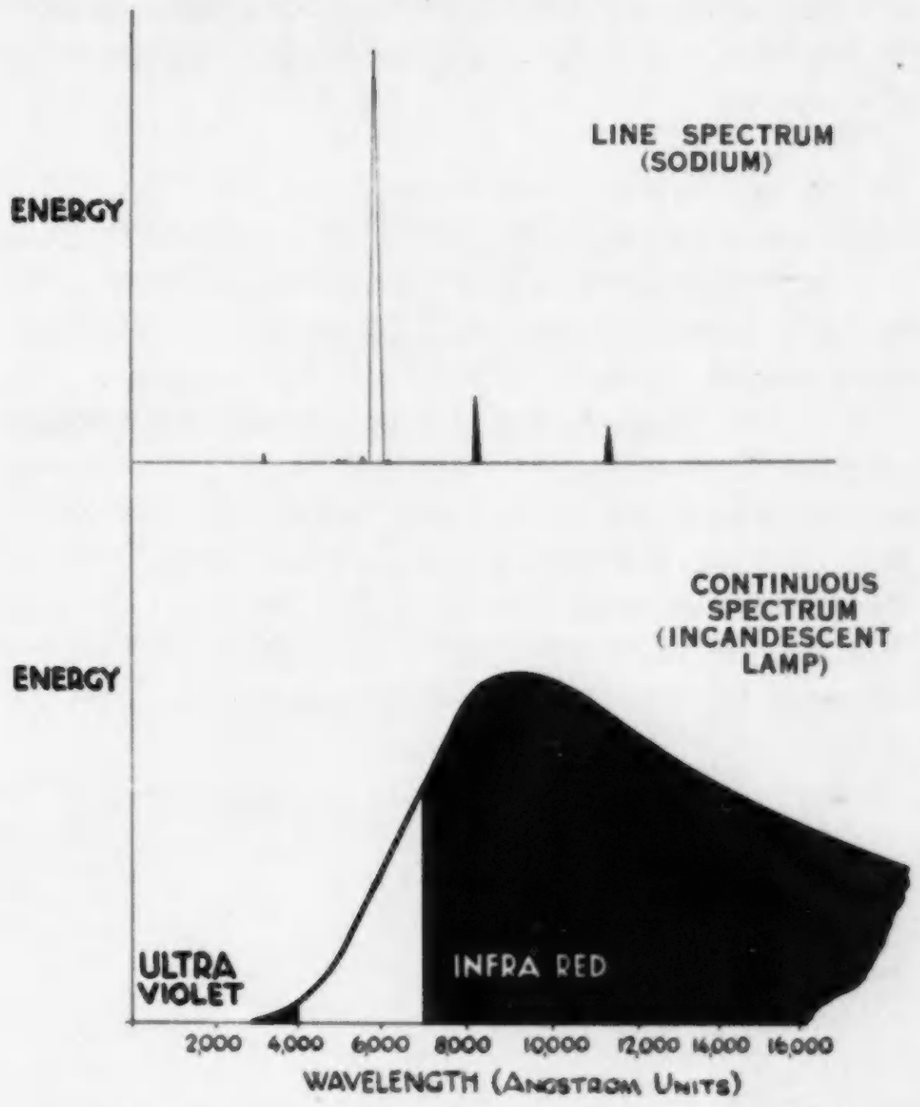


Fig. 8.—Energy distribution in continuous and line spectra (not to same scale).

through the vapour in our tube, the sodium ions so produced will have energies varying over a large range which must extend to a value at least as great as the ionisation potential 5.12 electron-volts. In consequence all the lines shown in the table and many other invisible ones will be emitted. The various lines will not all be of the same intensity; in fact, with sodium, all the visible radiations other than the D lines at 5,890 are very weak indeed. For example, the green lines at 5,685 have an intensity of only about one per cent of the yellow D lines.

We cannot enter here into the theory of the intensities of the lines. This is rather abstruse, but there is one important point to remember and to which we shall have occasion to return later. The fact that the relative intensity of the various spectrum lines changes with both the current and the pressure of gas in the tube.

We must have very clearly in our minds that the discharge between the electrodes is not uniform. It consists essentially of two parts—that immediately surrounding the metal electrodes, and that which constitutes the main column between them. It is the latter which gives most of the light, and is the part we want for luminous tubes. However, the complication of the other part of the discharge—that immediately surrounding the electrodes—cannot be avoided. This contributes more than any other factor to the difficulties of the manufacturer and designer, and, as a rule, governs the life of the tube.

Its better understanding and control has been responsible, more than anything else, for improvements which have taken place during the past five or six years.

COLD CATHODE TUBES.

First let us consider the high tension tubes, so widely used now for advertising and display. We will call these cold cathode tubes to distinguish them from others to be considered later.

If we trace the potential fall between the electrodes of one of these tubes when the current is passing, we find a sharp drop of voltage (known as the cathode fall) near the negative electrode, and then a uniform drop over the main luminous (or positive) column. The designer of a tube therefore needs to know both the value of the cathode fall and the voltage drop per

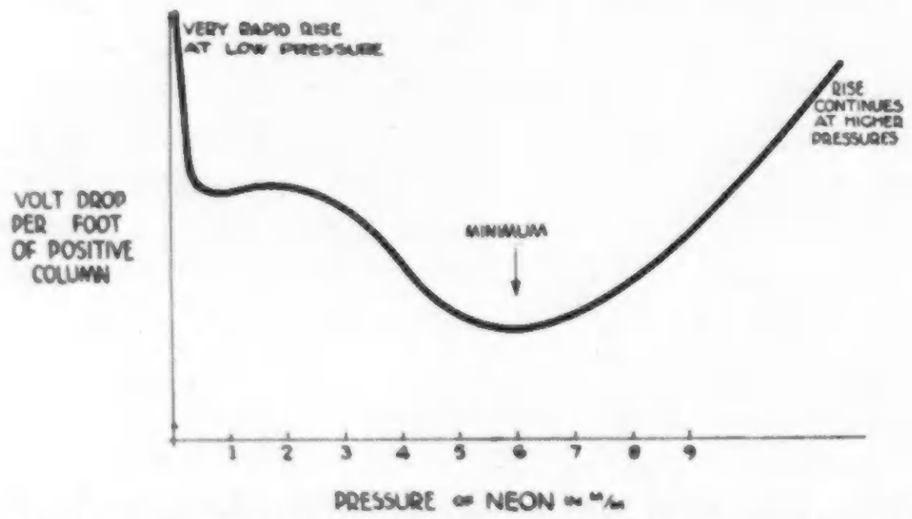

VERY RAPID RISE AT LOW PRESSURE
RISE CONTINUES AT HIGHER PRESSURES
VOLT DROP PER FOOT OF POSITIVE COLUMN
MINIMUM
1 2 3 4 5 6 7 8 9
PRESSURE OF NEON IN MM.

Fig. 9.—Volt drop in positive column at various pressures of neon.

unit length of the positive column. The sum of these will give him the voltage required to run the tube after it is once started.

The voltage drop along the positive column is not analagous to that along a wire carrying current since it varies inversely as the diameter, instead of inversely as the square of the diameter. Furthermore, Ohm's law is not obeyed and we find that the volt drop decreases as the current increases. It also varies in a complicated manner with the pressure of the gas inside it. Briefly, it is found that as the pressure is slowly decreased from a high value, the voltage drop decreases to a minimum value and then rises again; extremely rapidly at low pressures. In a 15 mm. diameter tube of the type we are considering, this minimum, with neon, occurs at about 6 mm. pressure and the very rapid rise takes place when the pressure has fallen below one millimetre.

The amount of the cathode fall depends upon various factors. When the current is such that the electrodes are just not completely covered with "glow" the cathode fall is called "normal." This normal cathode fall depends both on the gas used and on the material of which the electrode is made. Thus in neon gas the cathode fall is roughly 150 volts with iron electrodes, 140 volts with aluminium, and 120 with magnesium electrodes. On the other hand with iron electrodes, used with different gases, we find that the fall is 160 volts in helium, 150 in neon, 180 in argon, 270 in nitrogen, and nearly 300 in hydrogen. The normal cathode fall remains practically constant as the current is increased, until a time comes when the glow covers the whole cathode. If, after this, the current is raised any higher the fall is said to be in the abnormal state and may rise to several hundred volts. Tubes are generally designed to run at, or only slightly above, the normal cathode fall.

The following is a table of the volt drop per foot run, for pure neon gas:

R.M.S. volts per foot for a diameter of tube of 15 mm.—Neon.

Current mA.	6mm. pressure	12 mm. pressure.
25	147	159
35	134	144
45	126	135

With the information in this table and a knowledge of the cathode fall—we may calculate the volt drop over the tube. Thus, take iron electrodes with 180 volts cathode fall used in a 10 foot long tube running at 35 milliamps with a pressure of 6 mms. of neon. The volt drop would be $(134 \times 10) + 180 = 1{,}520$ volts.

A glance at the table shows that, as the current through the discharge increases, the volts across the tube go down. This is naturally unfortunate because there is nothing to prevent the current rising to catastrophic values unless the current is automatically limited by some external agency. This negative resistance effect is similar to that shown by the arc lamp.

The next important point to note is that the voltage required to start a discharge is greater than that required to maintain it. In the example we

have just considered, in which a little over 1,500 volts is required to run the discharge when once started, somewhere about 5,000 volts R.M.S. are needed to start the discharge. It is obvious that a tube designed to run at 1,500 volts would pass hundreds of amperes if 5,000 volts were permanently applied to it. The automatic limitation of the current can be achieved by using a choke coil in the primary of the transformer, or better, by designing transformers with magnetic leakage, so that the voltage automatically drops as soon as the tube strikes up and the discharge begins to pass.

FACTORS AFFECTING THE LIFE OF TUBES.

We must now consider more carefully the phenomena in the immediate neighbourhood of the cathode and their influence on the behaviour and design of discharge tubes. As already stated, this largely determines the life of a tube for the following reasons.

During the passage of a discharge a phenomenon known as cathodic sputtering takes place, which is the more vigorous the higher the cathode fall. This is something akin to evaporation, only instead of being due to the metal being at a high temperature it is produced by the impact of positively charged gas ions at the surface of the cathode. After a time this results in the formation of a film of metal on the glass walls surrounding the cathode, and, as the molecules of this film attach themselves to the glass they entrap gas atoms in the process. As the film grows it is therefore clear that the gas gradually disappears and the pressure inside the tube will decrease. We saw just now that once the pressure has fallen below one or two mm. the volts per foot will rise very rapidly until the discharge will no longer pass.

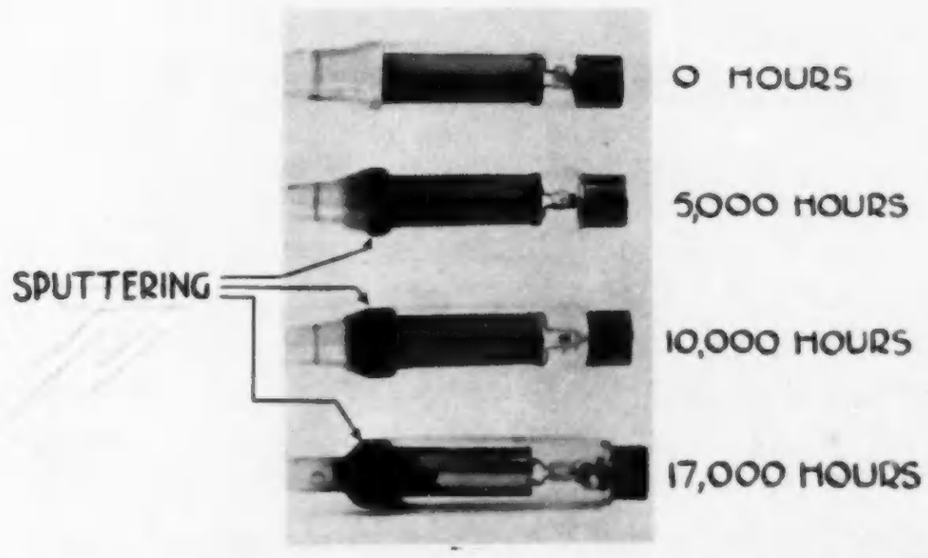


Fig. 10.—Appearance due to sputtering at various stages of life.

The rate at which this film is formed depends upon the current density at the cathode, so that for any given electrode size there will be a corresponding value of the current at which the tube will give a reasonable life.

How is the light output from the tubes influenced? The luminous efficiency is low at high pressures of gas. As the pressure is reduced the efficiency increases until a maximum is reached, after which it falls off very rapidly. The pressure for maximum efficiency depends on various factors—but with neon it is round about half a millimetre of mercury.

Naturally one would wish to work as near this pressure as possible, but considerations of the sputtering, which increases very rapidly as the pressure decreases, forces the use of higher pressures than this. In advertisement sign tubes, when very long lengths are required, pressures of several millimetres of mercury are generally used.

So far as concerns the total light given by a tube, it may be said roughly that in the case of neon, for example, the candle power increases proportionally to the energy dissipated in the discharge itself. Since the voltage across the tube decreases slightly with increasing current, it follows that as the current is increased the resulting light is not quite so great as would be expected if it was strictly proportional to the current.

HOT CATHODE TUBES.

The discharge tubes which we have been considering up to now, although ideal for advertisement signs where we want to see the long sources of light themselves, are not of so much value for general illumination purposes, where we usually hide the source of light itself and allow its rays to illuminate and reveal the surrounding objects. This is firstly because these tubes require high voltages and secondly because of the relatively small amount of light w eans that f 1 inconven afford adequa Moore tubes hting, and si pro- ducing o not know where concer ans of optica at the object vn the bright long length erefore yield ystem. Howe ly and efficie eloped. C es is a tube output per foot run. Now the light increases as the current increases, but we cannot increase the current in cold cathode tubes without shortening the life of the tube owing to sputtering—unless we do it by increasing the area of the electrodes. But to do this effectively we should need electrodes one hundred times the

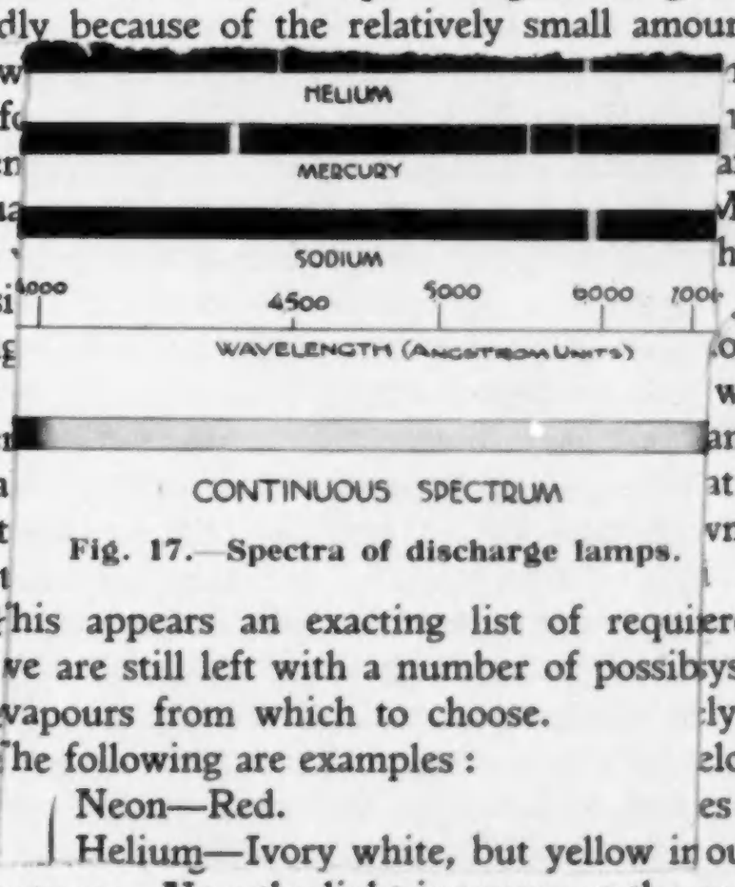


Fig. 17.—Spectra of discharge lamps.

his appears an exacting list of requi
we are still left with a number of possib
vapours from which to choose.
he following are examples :

- Neon—Red.
- Helium—Ivory white, but yellow in

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We must have very clearly in our minds that the discharge between the electrodes is not uniform. It consists essentially of two parts—that immediately surrounding the metal electrodes, and that which constitutes the main column between them. It is the latter which gives most of the light, and is the part we want for luminous tubes. However, the complication of the other part of the discharge—that immediately surrounding the electrodes—cannot be avoided. This contributes more than any other factor to the difficulties of the manufacturer and designer, and, as a rule, governs the life of the tube.

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If we trace the potential fall between the electrodes of one of these tubes when the current is passing, we find a sharp drop of voltage (known as the cathode fall) near the negative electrode, and then a uniform drop over the main luminous (or positive) column. The designer of a tube therefore needs to know both the value of the cathode fall and the voltage drop per

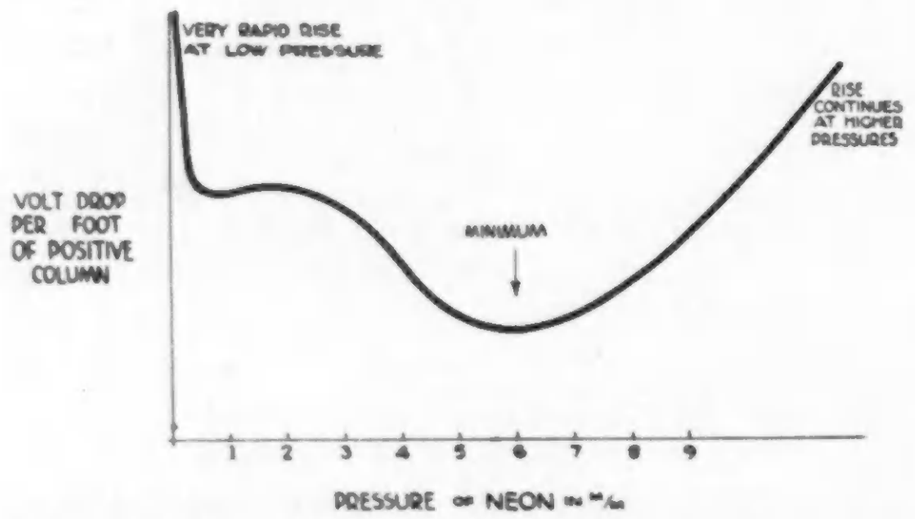

Fig. 9.—Volt drop in positive column at various pressures of neon.

unit length of the positive column. The sum of these will give him the voltage required to run the tube after it is once started.

The voltage drop along the positive column is not analagous to that along a wire carrying current since it varies inversely as the diameter, instead of inversely as the square of the diameter. Furthermore, Ohm's law is not obeyed and we find that the volt drop decreases as the current increases. It also varies in a complicated manner with the pressure of the gas inside it. Briefly, it is found that as the pressure is slowly decreased from a high value, the voltage drop decreases to a minimum value and then rises again; extremely rapidly at low pressures. In a 15 mm. diameter tube of the type we are considering, this minimum, with neon, occurs at about 6 mm. pressure and the very rapid rise takes place when the pressure has fallen below one millimetre.

The amount of the cathode fall depends upon various factors. When the current is such that the electrodes are just not completely covered with "glow" the cathode fall is called "normal." This normal cathode fall depends both on the gas used and on the material of which the electrode is made. Thus in neon gas the cathode fall is roughly 150 volts with iron electrodes, 140 volts with aluminium, and 120 with magnesium electrodes. On the other hand with iron electrodes, used with different gases, we find that the fall is 160 volts in helium, 150 in neon, 180 in argon, 270 in nitrogen, and nearly 300 in hydrogen. The normal cathode fall remains practically constant as the current is increased, until a time comes when the glow covers the whole cathode. If, after this, the current is raised any higher the fall is said to be in the abnormal state and may rise to several hundred volts. Tubes are generally designed to run at, or only slightly above, the normal cathode fall.

The following is a table of the volt drop per foot run, for pure neon gas:

R.M.S. volts per foot for a diameter of tube of 15 mm.—Neon.

Current mA.	6mm. pressure	12 mm. pressure.
25	147	159
35	134	144
45	126	135

With the information in this table and a knowledge of the cathode fall—we may calculate the volt drop over the tube. Thus, take iron electrodes with 180 volts cathode fall used in a 10 foot long tube running at 35 milliamps with a pressure of 6 mms. of neon. The volt drop would be $(134 \times 10) + 180 = 1{,}520$ volts.

A glance at the table shows that, as the current through the discharge increases, the volts across the tube go down. This is naturally unfortunate because there is nothing to prevent the current rising to catastrophic values unless the current is automatically limited by some external agency. This negative resistance effect is similar to that shown by the arc lamp.

The next important point to note is that the voltage required to start a discharge is greater than that required to maintain it. In the example we

have just considered, in which a little over 1,500 volts is required to run the discharge when once started, somewhere about 5,000 volts R.M.S. are needed to start the discharge. It is obvious that a tube designed to run at 1,500 volts would pass hundreds of amperes if 5,000 volts were permanently applied to it. The automatic limitation of the current can be achieved by using a choke coil in the primary of the transformer, or better, by designing transformers with magnetic leakage, so that the voltage automatically drops as soon as the tube strikes up and the discharge begins to pass.

FACTORS AFFECTING THE LIFE OF TUBES.

We must now consider more carefully the phenomena in the immediate neighbourhood of the cathode and their influence on the behaviour and design of discharge tubes. As already stated, this largely determines the life of a tube for the following reasons.

During the passage of a discharge a phenomenon known as cathodic sputtering takes place, which is the more vigorous the higher the cathode fall. This is something akin to evaporation, only instead of being due to the metal being at a high temperature it is produced by the impact of positively charged gas ions at the surface of the cathode. After a time this results in the formation of a film of metal on the glass walls surrounding the cathode, and, as the molecules of this film attach themselves to the glass they entrap gas atoms in the process. As the film grows it is therefore clear that the gas gradually disappears and the pressure inside the tube will decrease. We saw just now that once the pressure has fallen below one or two mm. the volts per foot will rise very rapidly until the discharge will no longer pass.

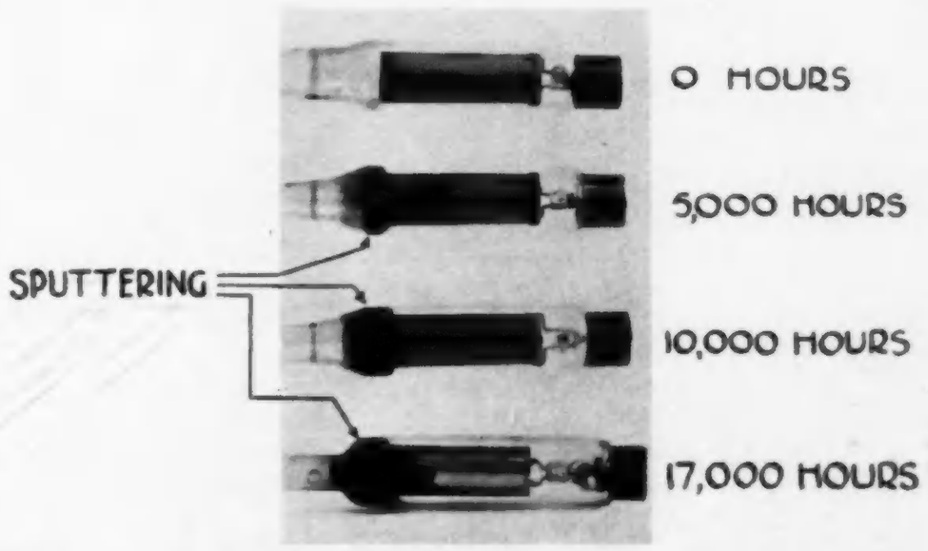

Fig. 10.—Appearance due to sputtering at various stages of life.

The rate at which this film is formed depends upon the current density at the cathode, so that for any given electrode size there will be a corresponding value of the current at which the tube will give a reasonable life.

How is the light output from the tubes influenced? The luminous efficiency is low at high pressures of gas. As the pressure is reduced the efficiency increases until a maximum is reached, after which it falls off very rapidly. The pressure for maximum efficiency depends on various factors—but with neon it is round about half a millimetre of mercury.

Naturally one would wish to work as near this pressure as possible, but considerations of the sputtering, which increases very rapidly as the pressure decreases, forces the use of higher pressures than this. In advertisement sign tubes, when very long lengths are required, pressures of several millimetres of mercury are generally used.

So far as concerns the total light given by a tube, it may be said roughly that in the case of neon, for example, the candle power increases proportionally to the energy dissipated in the discharge itself. Since the voltage across the tube decreases slightly with increasing current, it follows that as the current is increased the resulting light is not quite so great as would be expected if it was strictly proportional to the current.

HOT CATHODE TUBES.

The discharge tubes which we have been considering up to now, although ideal for advertisement signs where we want to see the long sources of light themselves, are not of so much value for general illumination purposes, where we usually hide the source of light itself and allow its rays to illuminate and reveal the surrounding objects. This is firstly because these tubes require high voltages and secondly because of the relatively small amount of light w eans that fo n inconven afford adequa Moore tubes hting, and si pro- ducing o not know where concer ans of optica at the object vn the brigh long length erefore yield ystem. Howe ly and efficie eloped.

C es is a tube output per foot run. Now the light increases as the current increases, but we cannot increase the current in cold cathode tubes without shortening the life of the tube owing to sputtering—unless we do it by increasing the area of the electrodes. But to do this effectively we should need electrodes one hundred times the

even more simple for the user. First, all Gecophone receivers are entirely self-contained. Moreover, the number of dials has been reduced to an effective minimum by utilising a single drive to operate two or more controls simultaneously, while the reception of any required programme is made easy by the calibration of station names on an illuminated dial.

Technical improvements naturally have been linked with valve developments. The use of high conductance valves and the adoption of the screen grid detector in all receivers have led to each single stage giving a better performance. Effective use has been made of variable-mu valves and band pass filters to achieve the highest degree of selectivity compatible with really good reproduction at ample volume.

Some of the trends of design in power equipments are of importance. Electrolytic condensers have been incorporated in power and smoothing circuits for the first time, affording an extremely high capacity in a very small space at low cost. Loud speaker field windings have been employed as smoothing chokes, which effects the double economy of using the high tension supply to energise the loud speaker, and the loud speaker windings to smooth the high tension.

EMPIRE BROADCAST SCHEME.

The inauguration of the Empire Broadcast Scheme has created a rapidly increasing demand for short wave apparatus from overseas. For this purpose an A.C. mains superheterodyne receiver (overseas model) has been developed, which is capable of very long distance reception over the whole of the short wave-band used for these transmissions, in addition to covering the medium wave-band from 200 550 metres.

As an allied line of some moment, there has been designed and manufactured conversion equipment suitable for the operation of D.C. mains apparatus after a supply system has been changed to alternating current. This equipment should prove of value owing to the large number of areas which have recently changed over both in this country and abroad.

As far as sound reproducing equipment is concerned, an entirely new range of apparatus is available, far too comprehensive to be outlined in the space here available, but reference should be made to a power amplifier of only two stages, capable of working direct from a carbon microphone and having an output of 6½ watts (A.C.). It gives straight line amplification between 50 8,000 cycles. Complete installations suitable for hospital or radio relays have also been designed, and the range of this class of equipment for indoor or outdoor use covers all reasonable requirements.

PHOTOELECTRIC CELL EQUIPMENT.

Great strides have been made in the development of photoelectric cells and their application to industry. One of the most interesting is their use in talking film equipments. Several alternative types of the caesium-on-silver cells have been produced for this purpose. Other applications for which equipment has been designed include television apparatus, newspaper telegraphic instruments, detection of atmospheric impurity, the control of lighting signs, the timing of greyhound races, the protection of papermaking machinery in the event of breakages of the paper, also the counting of motor tyres, steel tubes, packages of various kinds, etc. The applications of photoelectric cell are so numerous and of so varied a character that it would be quite impossible to convey in an article like the present any idea of the apparatus involved and its many-sided functions; but the following brief detail of an equipment recently installed in Stewart & Lloyds tube works is typical of possibilities.

The process of manufacturing welded steel tubes requires very rapid handling of the hot steel strip from which these tubes are rolled, right from the moment when the heated strip is pulled out of the furnace with a temperature of over 1,350 C to the end of the process when the finished tube moves down the cooling rack at the other end of the tube mill plant.

Tubes of this description are usually from 15 ft. to 18 ft. in length, and the time interval between the rolling of the tubes in the most up to date process is a matter of a few seconds. The tubes, after they have passed through the sizing rolls, run at a considerable speed down a trough, and are automatically transported to the cross rolls for hot straightening. After they have passed the cross rolls they move on to a cooling bank, dropping into a collecting cradle, whence they are taken away in bundles by means of overhead transporters to the finishing shops for cutting into lengths, testing, screwing, etc., before going into the warehouse for despatch.

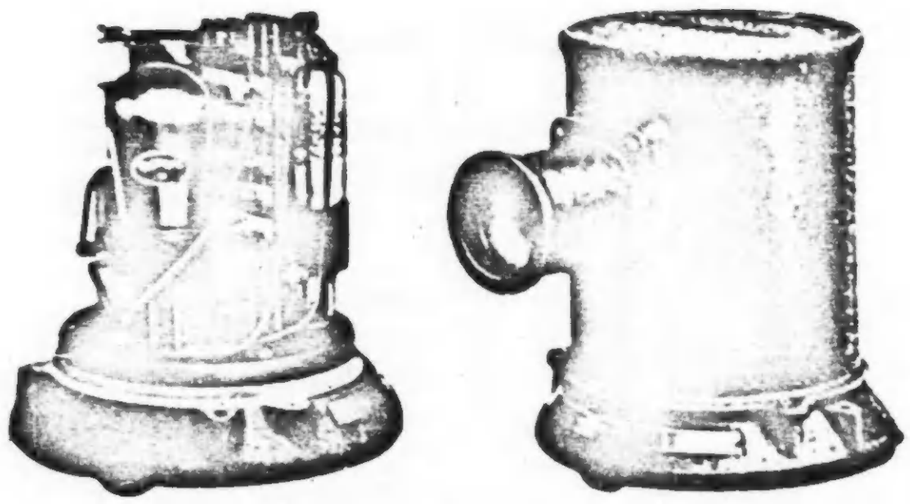

Fig. 66.—Internal and external views of photocell and amplifier.

Owing to the rapidity with which the tubes

follow one another through the sizing rolls and the cross rolls, the operation of releasing them from the cross rolls to the cooling bank is one which demands constant watchfulness and prompt action on the part of the operator. This will be realised from the fact that the distance between the tail end of one tube and the nose of the next following tube is often only about three feet. The slightest error in timing by the operator will result in a temporary stoppage due to collision between the tubes. Mechanical means to check these operations and to prevent the tubes from colliding or being sent forward into the cross rolls before the preceding tube had been cleared have failed. The reason for the failure was that any lever or electrical appliance that was struck by the hot tubes travelling at a great speed in rapid succession was damaged by the impact within a very short period of time.

The whole matter was therefore investigated by the G.E.C. with a view to developing photocell equipment for carrying out these operations efficiently. It was found that the radiation given out by these hot tubes will operate a photoelectric cell placed within a few feet of the tubes as they travel from the sizing rolls through the cross rolls to the cooling bank. The current set up in the photocell is amplified by an Osram valve, and relays operate an electrical contactor, which closes the circuit of a powerful solenoid. By means of the solenoid, the releasing shutters, which were originally operated by hand, are automatically operated at exactly the right moment, and by this means collisions of tubes, etc., are prevented.

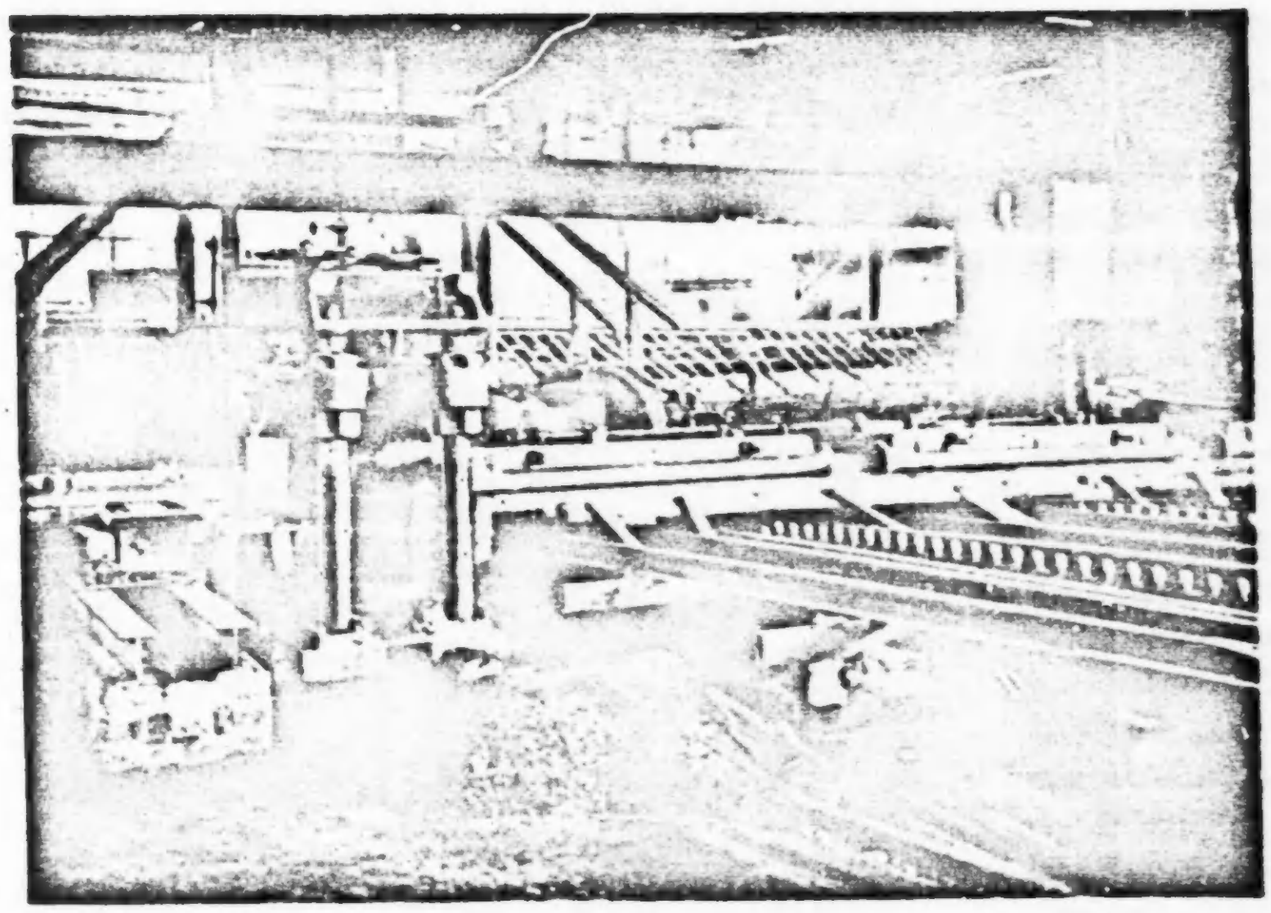

Fig. 67.—Photocell equipment installed at Stewart & Lloyds tube mills.

At the same time each tube is counted in a similar way by means of its radiation being picked up by another photocell equipment which operates a solenoid operated counter. Further, optical warning signals, consisting of red and green lights, are installed to indicate to the men at the furnaces and the racks when the line is safe for sending along another tube, or when the passage is blocked.

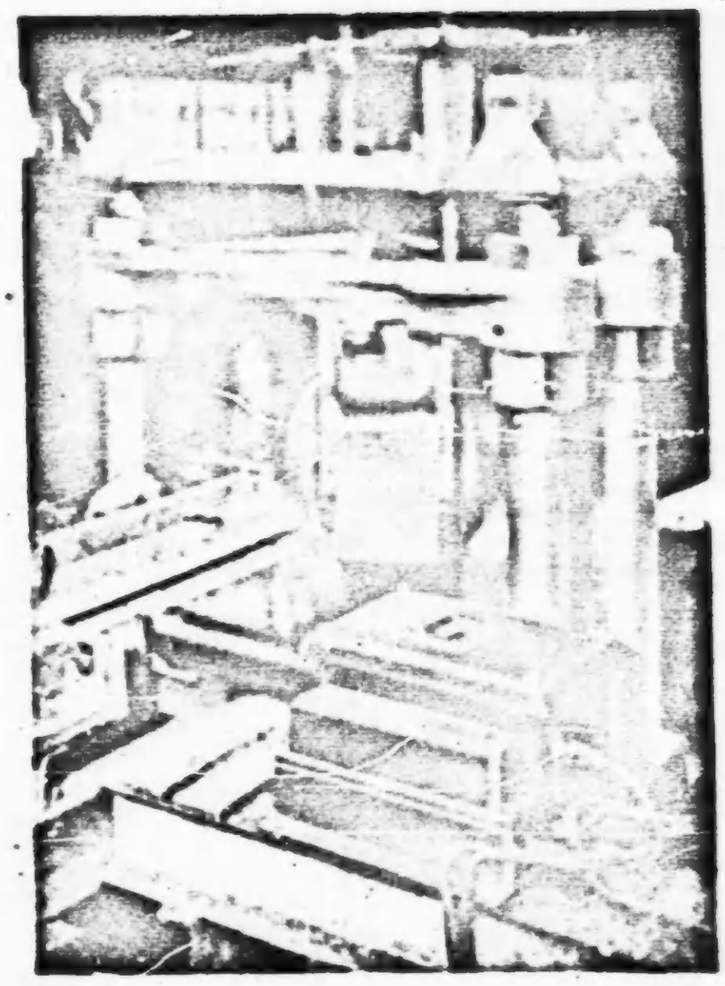

Fig. 68.—Detail view of photocell equipment seen in fig. 67.

Provision can also be made, when desired, to test the actual temperature of the hot strips when leaving the furnace, or of the tube at any time of its travel, by means of photoelectric temperature recorders.

INSTRUMENTS AND TESTING SETS.

The principal results achieved in connection with electrical instruments have led to improved construction and greater efficiency; further, existing types have been applied to a wider range of purposes.

Employing the well known fact that the resistance of a column of liquid varies with its purity, an instrument has been developed to indicate purity of liquids; the purity of water is frequently tested in this way. Across a supply of known voltage is placed a millammeter, moving coil for D.C. supplies, and a rectifier and moving coil instrument combination for A.C. supplies, in series with two electrodes, which are a specified distance apart in the liquid under test. With a pure liquid an indication is obtained which varies as the purity decreases. To protect the instrument against damage due to complete failure of the resistance of the

liquid, two small lamps are also inserted in series with the electrodes.

A small rectifier attachment incorporating a metal oxide rectifying unit has been developed, by which the range of usefulness of the well known No. 4 G.P.O. Detector can be increased. By the addition of this unit readings can be taken up to 15 m.a. and 150 or 300 volts A.C.

Another new device consists of an ohm-meter employing thermionic valves for testing insulation resistance values at 500 and 1,000 volts D.C., giving indications direct in ohms on a calibrated scale. The source of supply is 230 volts A.C., and the valves employed to give full wave rectification are one Osram U.14 and two Osram GU.1 valves for the 500 and 1,000 volts tests respectively. A push switch is arranged to change over from one voltage

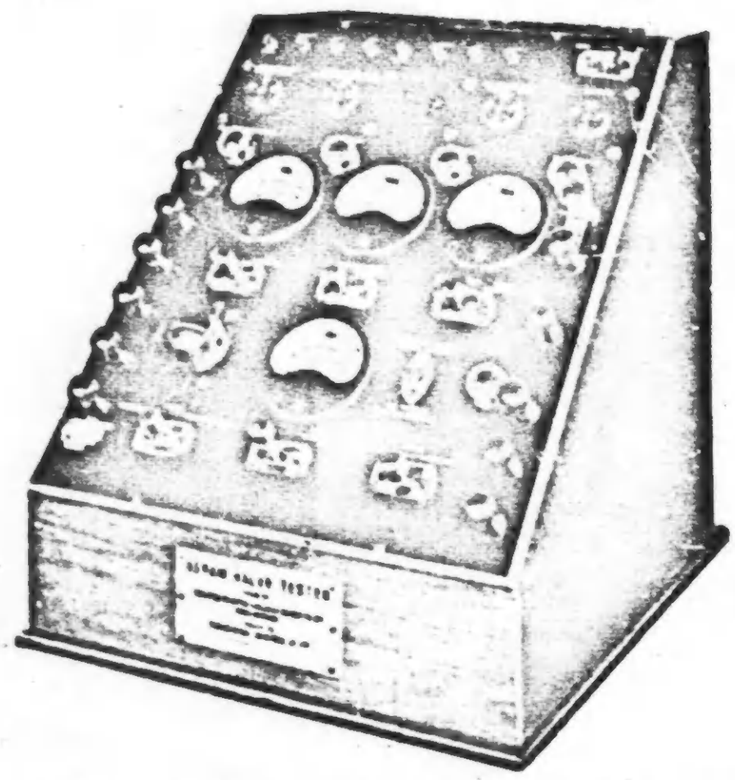

Fig. 69.—"Salford" valve testing equipment.

to the other. A portable pattern has also been manufactured, but the test voltage is 500 volts D.C.

For testing thermionic valves, both rectifying and radio receiving types, a test set has been designed which is so arranged that any type of valve at present on the market can be tested with the minimum amount of labour, the operator merely having to change switching positions (fig. 69).

ELECTRICITY METERS.

An important addition to the Chamberlain & Hookham range of meters is an alternating current meter for single phase circuits (fig. 70). It possesses the advantages of small size and light weight, yet gives an improved performance in comparison with earlier types. Its losses are very low. It has the present day long range of load characteristic. The adjustments are very simple, and, being provided with indicators, the work of recalibration in meter test rooms is rendered very much simpler than heretofore.

The increasing introduction of two-part tariffs by electricity supply authorities has created a demand for a suitable meter for dealing with prepayment consumers in those areas where this class of tariff is applied. In consequence there has been developed a two-part tariff prepayment meter (fig. 71), which

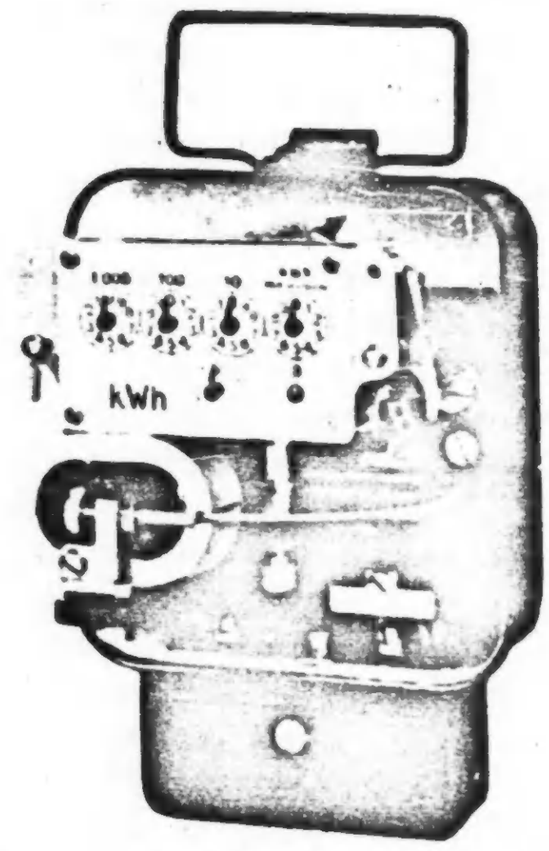

Fig. 70. Chamberlain & Hookham A.C. meter for single phase circuits.

is entirely suitable for such consumers. It consists of an addition to the standard prepayment mechanism, whereby a standing charge of any desired amount within limits may be collected. The whole of the apparatus is housed in a case uniform in size with the standard prepayment meter. The addition comprises a dial reading to 20 shillings or alternatively 40 shillings, and an adjust-

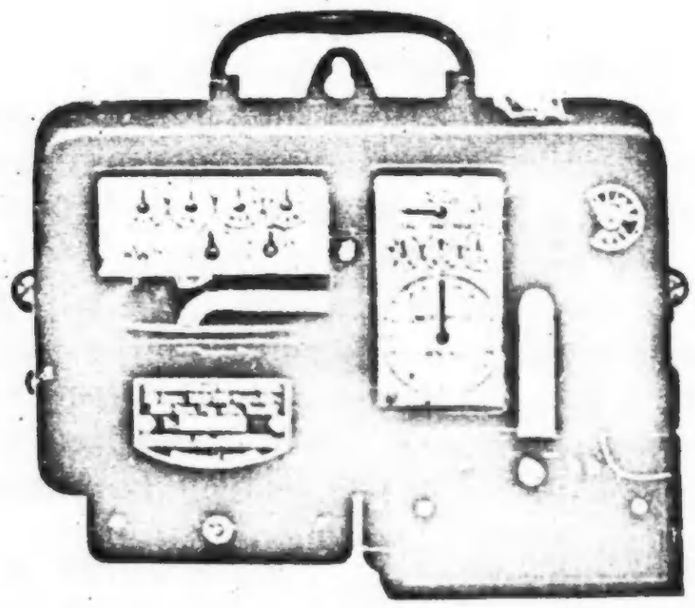

Fig. 71.—Chamberlain & Hookham two-part tariff meter.

able index whereby the amount of standing charge to be collected from the consumer during the succeeding collecting period may be set. The setting of the index is performed by the meter reader, who inserts a key through the meter cover and turns the index into the appropriate position. This operation can only be accomplished when the

coin drawer is removed; at other times the key-hole is inaccessible.

The meter functions in the following manner. The standing charge is set by inserting a key through

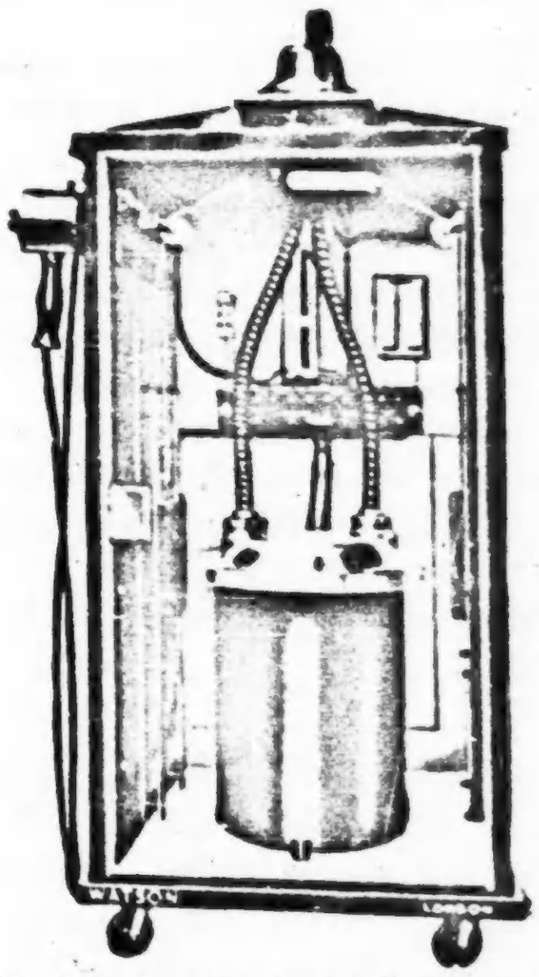

Fig. 72.—Shockproof dental X-ray equipment.

a hole situated behind the metal strip below the coin operating handle. Each time the consumer inserts a shilling, a portion of its value is allocated by the mechanism towards the cancellation of the standing charge, and the balance provides for a limited supply of current. The amount allocated to standing

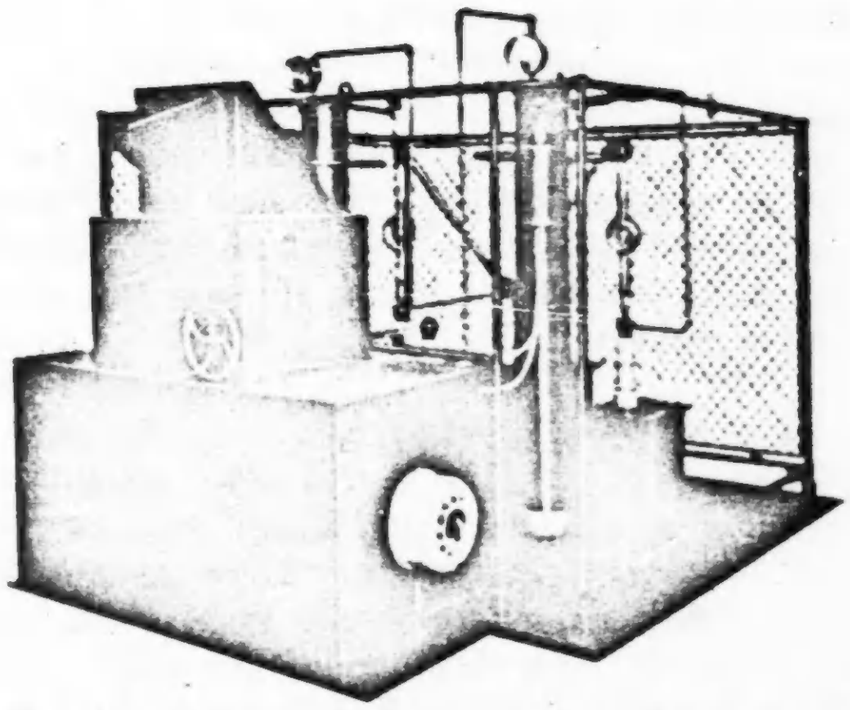

Fig. 73.—X-ray equipment for examination of steel specimens.

charge is deduced from the reading on the standing charge dial, the index of which shows the arrears outstanding. The balance of each coin inserted advances the "coins unused" index a suitable amount, and this in turn travels back towards zero as current is used.

In due course, after a sufficient number of coins have passed into the meter, the standing charge index will reach zero point, indicating that the whole of the standing charge for the particular accounting period has been paid. From this point onwards, the whole of each coin inserted will be allocated to providing current at the low price per kW.h, and since no reduction is made for standing charge, the consumer will now have the benefit of an increased supply of current for each coin. This state of affairs will continue until the collector calls to empty the cash box, on which occasion he will set the standing charge index to the appropriate position for the ensuing quarter.

Special provision is made for cases where an

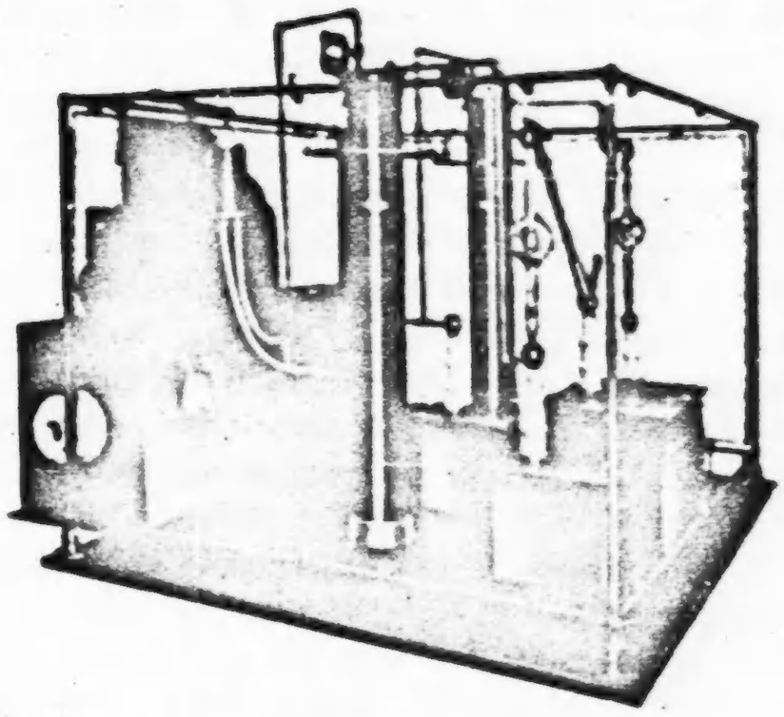

Fig. 74. Another view of the equipment shown in fig. 73.

unusually small quantity of current may be used. Suitable adjustments provide for variation in the price of current.

A portable testing set for testing polyphase meters on site fills a long felt want. It has been common practice in the past, when carrying out tests on site, to connect a check meter in series with the meter to be checked, leave the two running for several days, and then compare the readings of the two meters. This method does not give unqualified satisfaction, and in general the comparison only shows the average errors over a period without giving any indication of the errors at specified loads.

It usually happens that the load is not under the control of the testing engineer, more particularly if the test is being carried out in a generating station or a large industrial undertaking. The alternative to this method has been to remove the meter to the test room, and there carry out tests over the whole range of measurement and at various power factors. The objections to this alternative are that when the meter is disturbed an existing error may disappear or be modified, or conversely the disturbance may actually introduce an error. In any case, there is no

guarantee that the conditions of working on site will be reproduced in the testroom.

The portable polyphase meter testing set has therefore been designed with a view to removing these objections and enabling a complete series of tests to be carried out on site at any desired load and over a sufficient range of power factor to satisfy all practical requirements.

X-RAY APPARATUS.

During the year the development of X-ray apparatus carried out by Watson & Sons (Electro-Medical) Ltd., has been in two main directions, one being the development of shockproof diagnostic

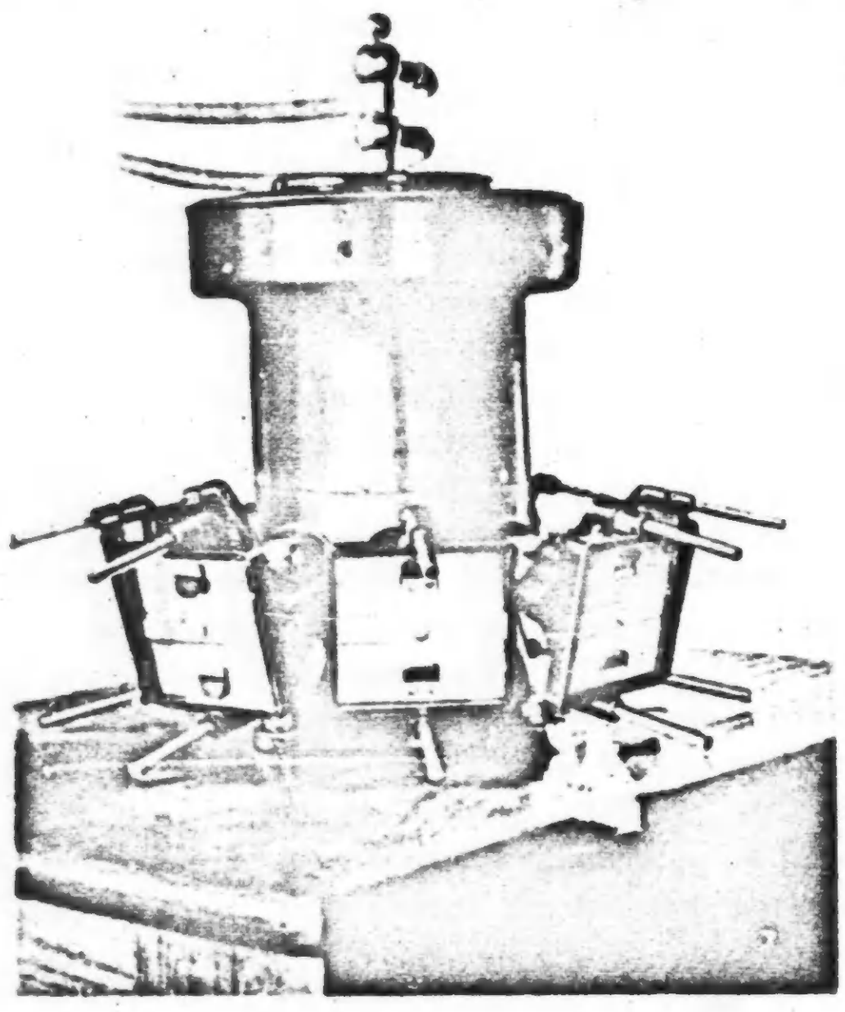

Fig. 75.—Crystallographic apparatus for examination of materials.

equipment and the other industrial equipment, both for radiometallography and crystallography.

An example of shockproof diagnostic apparatus is the Dental X-ray unit (fig. 72). The X-ray tube is enclosed in a small metal housing, the high tension being fed to the tube by flexible cable covered with an earthed metallic sheath.

The cabinet houses a small transformer capable of an output of 10 milliamperes at 45,000 volts R.M.S. The high tension cables are plugged into the top of this transformer, which is provided with a metal cover. A safety switch is fitted to the door.

New shockproof equipment for higher voltages is being developed, and a compact shockproof X-ray equipment is shortly being introduced, suitable for industrial radiography or medical deep therapy treatment, capable of giving 4 milliamperes at 200,000 volts.

Recent industrial apparatus manufactured includes an equipment supplied to U.S.S.R. (figs. 73 and 74). It consists of a high voltage constant potential generator capable of an output of 10 milliamperes at 200 kV direct current, together with a special X-ray tube box arranged for the examination of steel specimens by either direct visual observation or by radiography.

A recent development is a crystallographic apparatus arranged for examination of materials by the methods of either Laue or Debye-Shearer, or the powder method of Hull. The apparatus consists of a constant potential generator having an output of 30 milliamperes at 60 kilovolts direct current, together with a special research X-ray tube and turret containing the tube, which can be adapted for whichever method of analysis is preferred. An advantage of the equipment is that eight specimens can be examined simultaneously. The turret and cameras arranged for examination by the Laue method are shown in fig. 75.

In electro-medical work the main development has been the production of a valve diathermy apparatus for surgical work. This equipment is known as the "Chirotherm."

This is the only surgical diathermy apparatus of its kind made in this country, and possesses the unique distinction that with it, not only can coagulation be carried out, but fat, tissue and skin can be cut with great rapidity, and the healing is not marred by ill effects. Furthermore, the formerly serious objection of muscular contraction has in this machine been overcome.

BATTERIES.

A new dry cell of the paper lined pattern has been introduced. It is designed for tropical and hot climates, and where a high short circuit test current of the order of 40 amps or more is desired. The thinness of the paper lining, compared with the greater thickness of the more usual paste electrolyte, ensures that the maximum possible quantity of depolarising material is available. The paper is so treated that it is kept moist and saturated with electrolyte, so that drying up is completely eliminated. This cell possesses a long shelf-life and a very low internal resistance; it will give also a long life on an intermittent service.

MINING APPARATUS.

Several new patterns of mine-signalling apparatus, which meet with the approval of the Mines Department, have been developed. These include a new form of relay which is already installed in several mines, also a new mining magneto ringing telephone and a battery ringing mining telephone.

For shot firing in gaseous mines a new mine exploder is available. It is, in effect, a magneto electric machine, which is made in two designs, for

either high tension or low tension circuits. The device complies in every way with the latest mining regulations.

LUMINOUS SERVICE INDICATION.

The Magnet system of luminous service indication is the subject of continual improvement. The inconvenience of audible signals is well known, and even when the calls are recorded visually there are obvious limitations to effectiveness. The latest installations of the system provide indicating lamps, not only at the serving but at other suitable situations. Further, a visible record is given to the caller, showing that the signal is operating. The new features thus incorporated in the system are made possible by a new relay switch. The visible indication remains, even though the push circuits are open, until a lamp cap upon the relay is pressed.

ELECTRIC TORCHES.

The popularity achieved by the standard bakelite torch has led to the introduction of a focussing spotlight bakelite torch, which has an adjustable lamp to project a spot beam or general light as required. It is of interest that this torch has successfully withstood tropical conditions. In addition a miniature bakelite torch suitable for carrying in the pocket or in a lady's handbag has recently made its appearance.

ELECTRIC LIGHTING SWITCH AND FUSE GEAR.

The "Minor" fuseboard is an entirely new production for use on lighting circuits, and complies fully with Home Office requirements. The range available covers from two to ten double pole branch circuits. The board is contained either in a teak or a pressed steel case. The latter is finished in silverlac, a finish which is standard on G.E.C. lighting fuse boards, and presents an altogether better appearance than is usual with painted iron; moreover it offers a more lasting surface.

Two additions have been made to the range of switch-plugs. The first is a bakelite D.P. face entry 3-pin tumbler switch-plug, available in 5 and 15 ampere sizes, which combines the "Landor" quick make quick break switch movement with a 3-pin British Standard gauge face entry socket. The second addition is a D.P. 3-pin interlocked switch-plug, made in surface semi-recessed and flush patterns. It also incorporates the "Landor" quick make quick break switch movement and 3-pin British Standard gauge socket.

A novel form of lampholder for use in a new series lighting system for tram and train illumination consists of an Edison screw holder, in which the lamp cap operates a spring contact, which is arranged so that when the lamp is removed the holder is automatically short circuited, thus keeping the remainder of the series alight. It will be readily visualised that a lampholder of this kind has many applications apart from the particular system referred to.

A further step in the direction of safety has been made by the production of an Edison screw holder in which the thread has been moulded into the porcelain body. In this way, the copper shell, which is always a potential source of danger, has been eliminated, and contact is not fully made until the lamp is in position.

An intermediate pattern of the "Landor" quick make and quick break switch is available.

A safety shield has been developed for fitting to the range of "Landor" switches. This consists of a bakelite supplementary shield which can be locked in position underneath the ordinary cover over the terminals of the switch, so that if the outer cover should be removed no live metal is accessible.

The increasing popularity of bakelite for use in the manufacture of wall plugs is further exemplified in the production of two new lines of all-bakelite flush socket and plugs. These are being made 5 amp. 3-pin and 15 amp. 2-pin, and are designed for fixing in conduit boxes or direct to the skirting board.

MOULDED PRODUCTS.

Reference has been made in earlier sections of this article to the uses of bakelite in the construction of various classes of apparatus. It should not be overlooked that this material, together with many other moulded products, is made in a works at Witton which is specially reserved for moulded insulation. During the year this works has again been extended. One section of the extension is of particular interest, as it caters for the production of cabinets for the wireless sets manufactured at the G.E.C. Telephone Works and by other wireless manufacturers. Some of the types of cabinet represent the largest mouldings ever produced in this country, and involved the installation of bakelite presses which are the largest British presses yet produced for bakelite moulding work.

Luminous Discharge Tube Lighting.

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The article which follows reproduces in substance a lecture delivered by the author before the Illuminating Engineering Society at the Wembley Research Laboratories of the G.E.C. An account is given of the general principles underlying the working of discharge tubes, both of the older high-voltage type, and also the newer hot-cathode tubes which operate at ordinary lighting-mains voltages. The latest developments in the direction of practical lighting units of the latter kind are described.

Acknowledgment is made to the "Illuminating Engineer" for permission to reprint the article and to reproduce certain of the illustrations.

INTRODUCTION.

IT may be stated with confidence that the luminous discharge tube is to play a big role in electric lighting of the future. One bases this opinion more upon a broader survey of the physics of the subject than upon what has already been achieved in decorative and display lighting, noteworthy as this undoubtedly is. Whilst one cannot at present point with any certainty to a given combination of the many and complicated phenomena which are embraced by the term luminous discharge, and predict that this or that will be the line of big industrial advances — one can, without hesitation, say that the limits to progress set by theoretical considerations are, in the case of the discharge tube, far wider than physical laws permit in the case of the incandescent filament lamp. Perhaps this is particularly so when we consider efficiency. A light efficiency of many times that of the filament lamp is already certain. In colour the discharge lamp has a wide flexibility, although we cannot yet always achieve exactly what we want in reproducing the conditions which daylight imposes upon us. In geometrical form we shall have a much wider choice than the filament lamp can ever give. On the score of electrical simplicity nature has not been so kind to the gas discharge lamp. It is here probably that the filament lamp will ultimately have its chief bargaining point. But we must not lose our perspective. When in 1878, Swan first produced his electric lamp with its carbon filament about 1/8 inch diameter, and 1 inch long, if as much had been known about gas discharge tubes as we know to-day, what would have been the views of the experts on the question of which system would yield the most commercial 230 volt lamp? Would anyone have believed that a filament of the size of the thread of a spider's web could have been made to glow for 1,000 hours at a temperature of 2,700 degrees with no more than 1 per cent of failures before 500 hours? Would not everyone have pointed to the gas discharge lamp as the only promising avenue for electric lighting? It is true that the discharge lamp is to-day further advanced than the filament lamp was in Swan's day, but one must admit that to-day there is probably as much

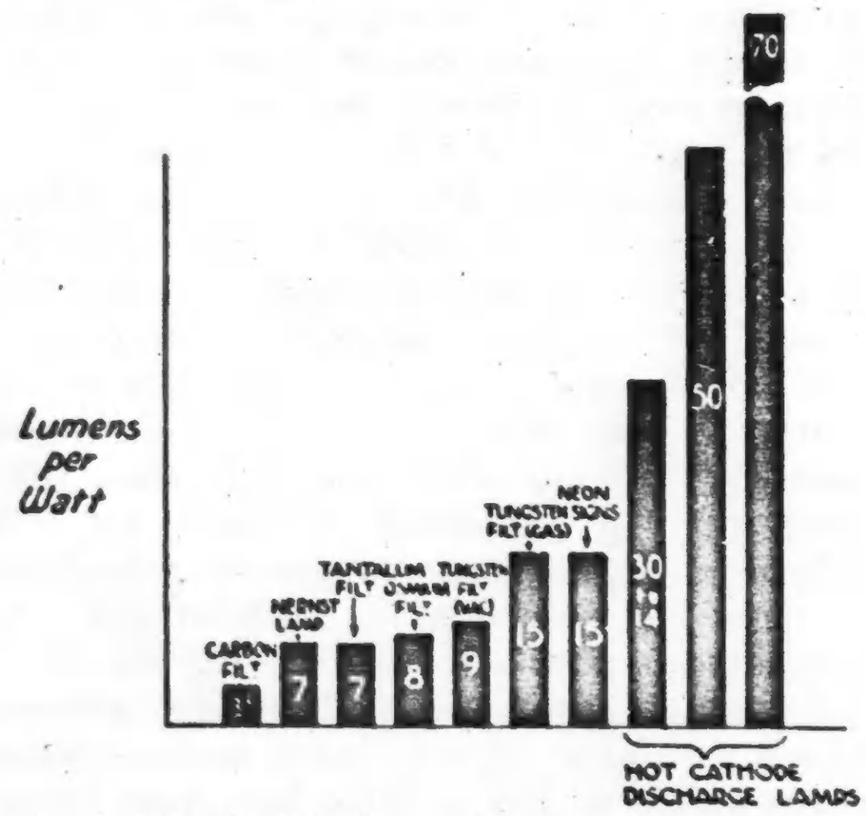

Fig. 1.—Efficiency of various lamps.

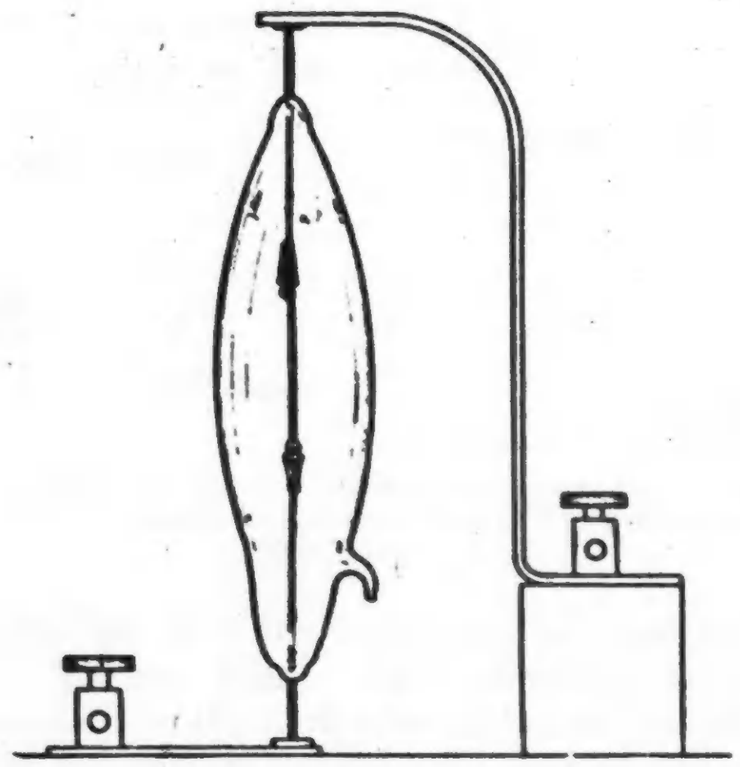

Fig. 2.—Swan's first incandescent lamp, 1878.

to find out in the theory and possibilities of the gas discharge lamp as in 1878 there was to discover in the filament lamp.

This is not predicting the early or even the ultimate substitution on a large scale of the present filament lamp by discharge lamps. The filament lamp is too simple and effective a product of engineering and scientific skill to be thus displaced. But the discharge lamp is certainly going to evolve its own field of usefulness and weave itself into our picture of electric lighting of the future.

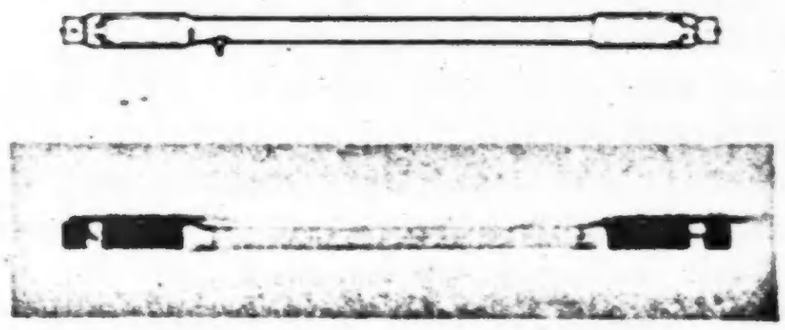

Fig. 3.—Simple form of gas discharge tube.

The object of this lecture is to explain those features and characteristics of discharge lamps which the engineer needs to grasp if he is to have the same intelligent appreciation of the way they function as he now has in the case of the filament lamp. No one who speaks to electrical engineers in these days needs to apologise for assuming a general knowledge of atomic physics. That has become as much a part of our intellectual stock-in-trade as Ohm's law was to the engineer of twenty years ago. Let us bear in mind, however, that there are still many engineers with us who learnt their engineering in Ohm's law days. Will any latter day engineers therefore overlook what will sometimes be an assumption in what follows

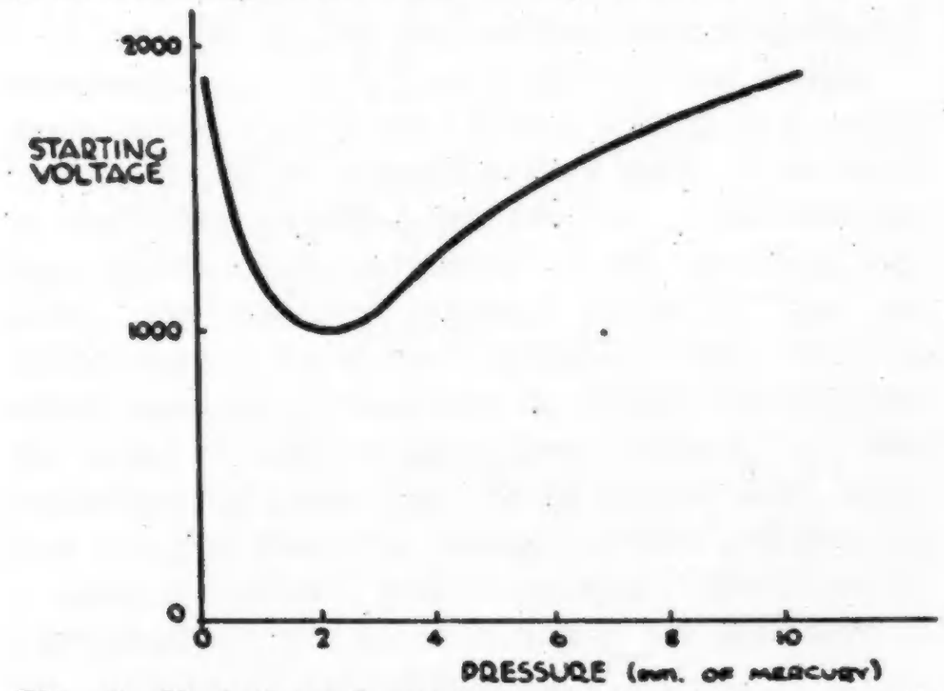

Fig. 4.—Variation of starting voltage with pressure in cold cathode neon tube.

of too little knowledge of the atom and its manner of emitting electro-magnetic radiation.

WHY DOES A TUBE RADIATE LIGHT?

We had better be clear first of all about what is meant by a gas discharge tube. For present purposes is meant a tube with transparent walls in which are two electrodes, one at each end, across which the voltage is applied. The gas in the tube is carefully controlled as to quantity and purity so that it radiates light as we want it to, under the influence of the current which passes through it from one electrode to the other.

In fig. 3 is such a tube. It is an example of the type used extensively for advertising signs. The first thing of course to notice is that, unlike an incandescent lamp, it has nothing visible connecting the two electrodes inside the tube. How then is current to pass and light to be radiated? The superficial answer is that the tube is filled with a gas at low pressure; it is this which both conducts the current and gives off the light. But it is vital to our intelligent understanding of the subject of discharge tubes that we should have a picture in our minds of the manner in which the gas does this. It will not, however, be possible to do more than give a very brief outline of this fascinating but most complicated process.

Except in extra high tension work, we are accustomed to think of the air as an insulator. Imagine the difficulties which we should encounter if it were even a moderate conductor at ordinary supply voltages. Refined measurements do, however, show that the air and other gases are not perfect insulators. An extraordinarily minute current does indeed flow between two electrodes in air even when the voltage is quite low. This current is, however, so small that it would need to be enormously magnified before it would be measurable

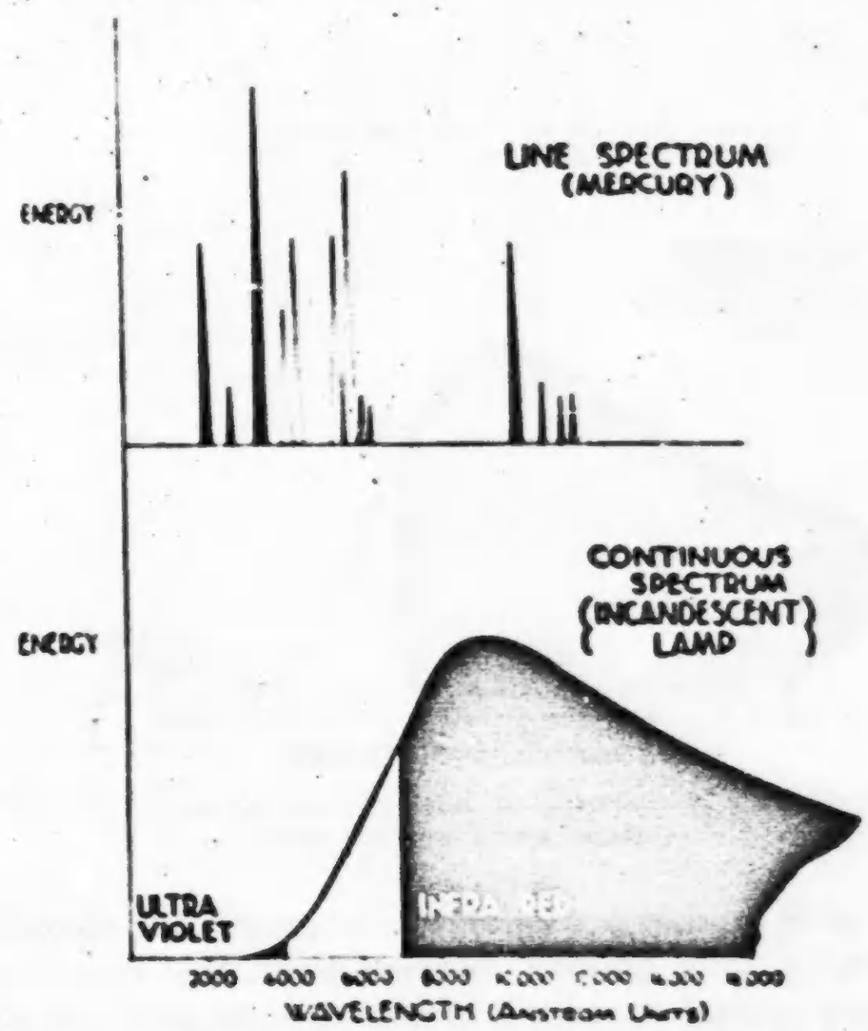

Fig. 5.—Energy distribution in continuous and line spectra (not to same scale).

on a sensitive galvanometer. Although utterly negligible in most work, it must not be thought to be unimportant. As a matter of fact, it was owing to the careful study of this minute conductivity of the air that the penetrating radiation from outer space, now known as the Cosmic rays, was discovered.

We have good reason to believe that if a gas could be completely shielded from this and other radiation or sources of ions, it would be strictly a

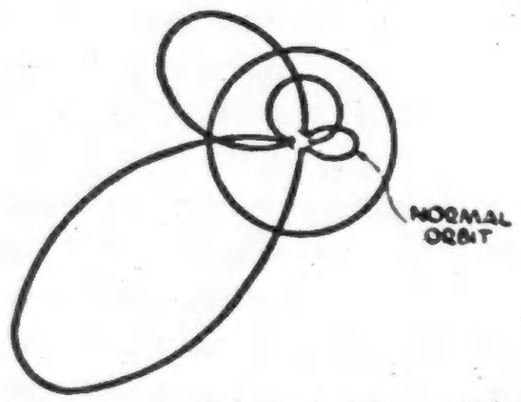

Fig. 6. Sodium atom : diagram of possible orbits of the valency electron.

perfect insulator. Actually, however, these Cosmic rays and other ionising agents produce about 100 ions per second in the 400 million million million molecules of gas present in every cubic inch of the air around us and also, of course, of the gas in our tube. If a small potential difference is applied to the electrodes these primary ions travel through the gas and constitute a very minute current. When the voltage is increased, a time comes when some of the ions in colliding with the gas atoms will produce other ions and these again still more. The number of ions thus rapidly increases at compound interest until the flow is so great that it constitutes an appreciable current. Our insulating gas has thus in effect become highly conducting. It is of interest, however, to realise that without these primary ions in the gas to start with, it would refuse to react to the voltages we apply to our tubes and there would be nothing to start up the complicated train of phenomena we are about to consider. We must not, however, suppose that the gas will behave as an ordinary metal conductor would do. We shall find that it does not obey Ohm's law and that it also behaves in other peculiar ways, some of which we shall touch on later. Before leaving the question of how the discharge starts and the gas becomes conducting, there is one further point to be cleared up. Why must the gas be at a low pressure?

If the gas in our tube were at atmospheric pressure, we should have to apply a potential of many hundred thousand volts before the discharge would start, and when it did, it would take the unwanted form of a spark. As we decrease the gas pressure, we find that the necessary starting voltage becomes considerably reduced. This is because the gas atoms are farther apart and the primary ions can thus gather more speed before collisions. At very low pressures, however, you will see that the voltage needed will rise again, since there are then comparatively few atoms present, so that the chance of ionisation becomes very small. The starting voltage of our gas discharge tube will thus be a minimum at a certain pressure which, in the case of neon gas, is of the order of a few millimetres of mercury. One other important point is that the visible form of the discharge changes as the pressure is reduced and instead of a spark we find that the tube becomes filled with a luminous glow.

Now for the second question. How is this light produced? A wire through which a current is passing does not emit light unless it is being heated by the current to a high temperature. Then the light emitted is just the same as if the wire had been heated to the same temperature by a flame instead of by a current. When analysed by a spectroscope the radiation will be found to be "continuous," that is, a certain amount of each wavelength will be found in it. The radiation from a luminous discharge in a gas or vapour is, in general, quite different from this. On analysis, only certain wavelengths, all highly characteristic of the gas, are found to be present.

A normal atom of a gas consists of a central positively charged nucleus round which negatively charged electrons revolve in certain orbits. Now suppose an electron or ion to be moving under the influence of the voltage gradient along our tube. We have seen that, as it moves, it is continually colliding with the gas atoms; actually a collision will take place about every tenth of a millimetre of its path when the gas is at the low pressure we are considering. So long as the velocity is small, which the ion has gathered in its fall through the voltage gradient along its track, it will rebound at each

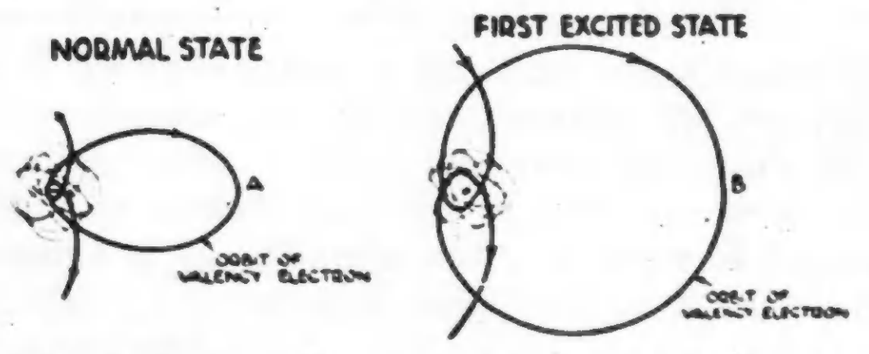

Fig. 7.—Sodium atom : an electron transition from orbit B to orbit A leads to the emission of the yellow sodium line 5890 A.U.

collision just as if the atom and ion were perfectly elastic billiard balls; their combined energy of motion will be the same after as before the collision. But as the voltage between the ends of the tube is increased, the velocity, and therefore the energy which the ion acquires in its fall, will also increase, and when this becomes greater than a certain critical value, an extraordinary thing happens. The whole of this critical amount of energy is used up in transferring one of the electrons revolving round the atom

to an exterior orbit not normally occupied by an electron. Any excess of energy over the critical amount needed for this, shows itself as kinetic energy of motion divided between the two bodies. The atom with its electron in an outer orbit is said to be in an excited state. However, it generally does not long remain in this abnormal condition; the outer electron soon returns to its normal orbit and in doing this the important thing happens. The energy which was absorbed in changing the orbit is now ejected as radiation. The additive effect of thousands of millions of atoms all behaving in similar ways gives us the radiation we observe from the tube. Radiation of what wavelength? The answer to this involves one of the most fundamental laws of modern physics. This remarkable relation, which to the physicist of to-day is what Ohm's law has been to the electrical engineer, states that the frequency of the radiation emitted is proportional to the energy emitted by the atom during the process of radiation.

Energy (E) = Planck's constant (h) × Radiation frequency (r).

Since a short wavelength corresponds to a high frequency and *vice versa*, we see that the higher the energy of an atom in the excited state, the shorter the wavelength of the radiation emitted when the electron returns to its normal orbit.

Now although we have only considered one critical energy value of excitation, all atoms have a vast number of such values corresponding to transitions of electrons to different orbits. Each kind of atom has its own characteristic set, and, when recovering from the excitation by ionic collisions, emits radiations having a corresponding set of wavelengths.

If the energy of the colliding ion is gradually increased, a point will be reached when it has so much energy that, instead of transferring an electron in the atom to an extreme outside orbit, it succeeds in completely expelling the electron. The collision then results in the formation of two new ions, the atom, now positively charged (since it has lost an electron), and the free negatively charged electron which has been ejected from it. When this happens the atom is said to have been ionised. If this ionisation has taken place in an electric field, these new ions dart down the voltage gradient and proceed to generate others, and these again still more by compound interest, thus initiating the discharge in the manner already described.

Before leaving the theoretical aspects of the discharge processes let us illustrate them by an example. Suppose our tube to contain sodium vapour at a low pressure. The critical energies and corresponding wavelengths for sodium are given in the following table. The energies are given in terms of the voltage difference, through which an electron must fall in order to acquire the corresponding energy. This gives a convenient energy unit known as the electron-volt.

Critical energy in electron-volts	Corresponding approximate wave-lengths	Type of radiation emitted
2.1	5,890 A.U.	Yellow (D)
3.2	11,400	Infra red
3.6	8,180	Infra red
4.1	6,160	Red
4.3	5,685	Green
.	.	.
.	.	.
.	.	.
5.12		Ionisation

If electrons are flowing through the vapour in circumstances such that they can never acquire an energy of more than 2.1 electron-volts (the first critical energy value) no light is emitted. But if we apply a potential sufficient to start a discharge

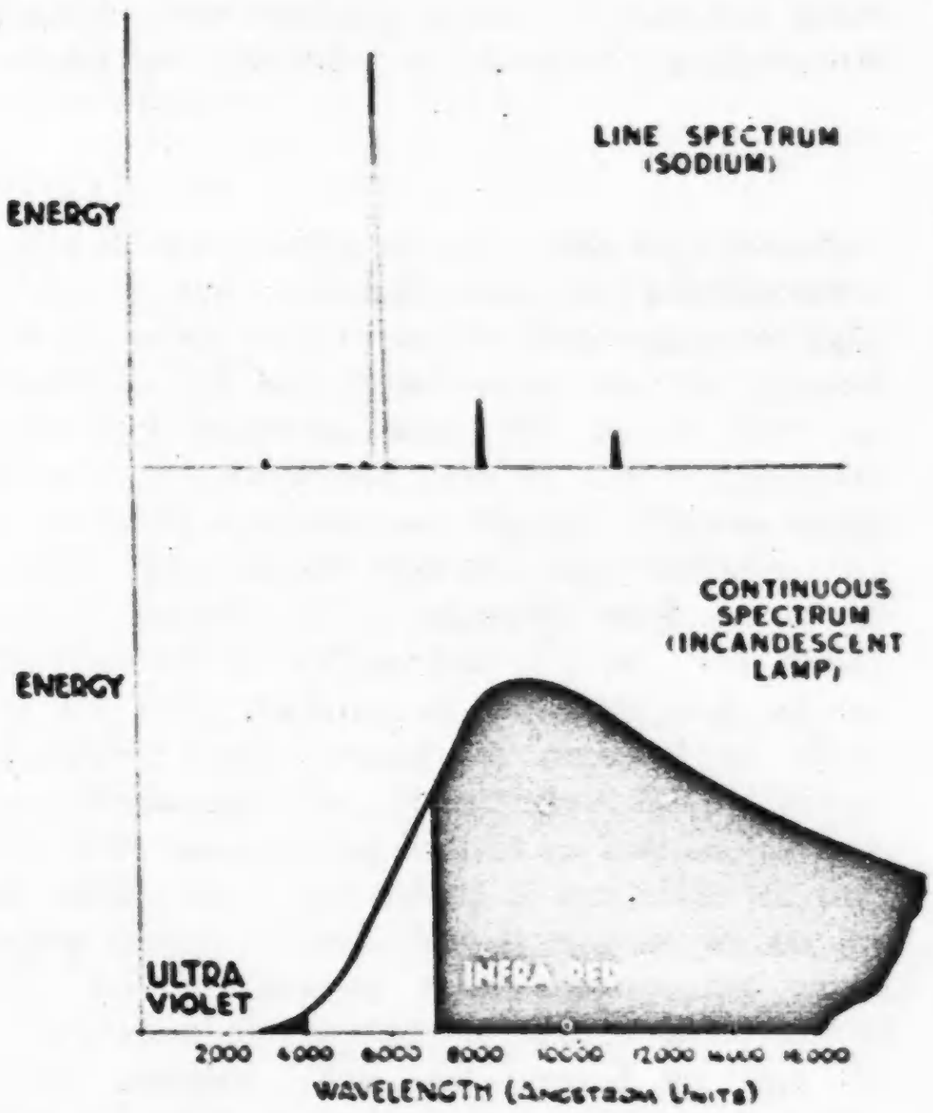

Fig. 8. Energy distribution in continuous and line spectra (not to same scale).

through the vapour in our tube, the sodium ions so produced will have energies varying over a large range which must extend to a value at least as great as the ionisation potential 5.12 electron-volts. In consequence all the lines shown in the table and many other invisible ones will be emitted. The various lines will not all be of the same intensity; in fact, with sodium, all the visible radiations other than the D lines at 5,890 are very weak indeed. For example, the green lines at 5,685 have an intensity of only about one per cent of the yellow D lines.

We cannot enter here into the theory of the intensities of the lines. This is rather abstruse, but there is one important point to remember and to wnich we shall have occasion to return later. The fact that the relative intensity of the various spectrum lines changes with both the current and the pressure of gas in the tube.

We must have very clearly in our minds that the discharge between the electrodes is not uniform. It consists essentially of two parts—that immediately surrounding the metal electrodes, and that which constitutes the main column between them. It is the latter which gives most of the light, and is the part we want for luminous tubes. However, the complication of the other part of the discharge—that immediately surrounding the electrodes—cannot be avoided. This contributes more than any other factor to the difficulties of the manufacturer and designer, and, as a rule, governs the life of the tube.

Its better understanding and control has been responsible, more than anything else, for improvements which have taken place during the past five or six years.

COLD CATHODE TUBES.

First let us consider the high tension tubes, so widely used now for advertising and display. We will call these cold cathode tubes to distinguish them from others to be considered later.

If we trace the potential fall between the electrodes of one of these tubes when the current is passing, we find a sharp drop of voltage (known as the cathode fall) near the negative electrode, and then a uniform drop over the main luminous (or positive) column. The designer of a tube therefore needs to know both the value of the cathode fall and the voltage drop per

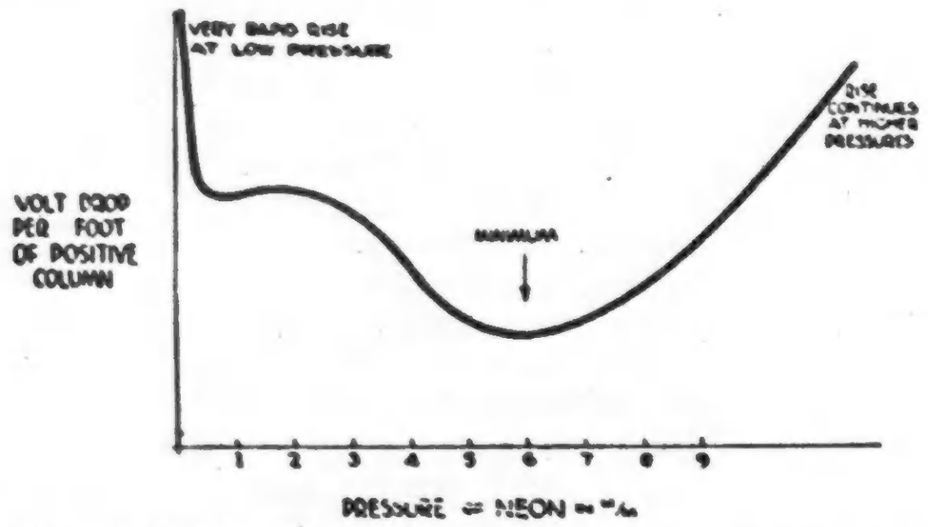

Fig. 9. Volt drop in positive column at various pressures of neon.

unit length of the positive column. The sum of these will give him the voltage required to run the tube after it is once started.

The voltage drop along the positive column is not analagous to that along a wire carrying current since it varies inversely as the diameter, instead of inversely as the square of the diameter. Furthermore, Ohm's law is not obeyed and we find that the volt drop decreases as the current increases. It also varies in a complicated manner with the pressure of the gas inside it. Briefly, it is found that as the pressure is slowly decreased from a high value, the voltage drop decreases to a minimum value and then rises again; extremely rapidly at low pressures. In a 15 mm. diameter tube of the type we are considering, this minimum, with neon, occurs at about 6 mm. pressure and the very rapid rise takes place when the pressure has fallen below one millimetre.

The amount of the cathode fall depends upon various factors. When the current is such that the electrodes are just not completely covered with "glow" the cathode fall is called "normal." This normal cathode fall depends both on the gas used and on the material of which the electrode is made. Thus in neon gas the cathode fall is roughly 150 volts with iron electrodes, 140 volts with aluminium, and 120 with magnesium electrodes. On the other hand with iron electrodes, used with different gases, we find that the fall is 160 volts in helium, 150 in neon, 180 in argon, 270 in nitrogen, and nearly 300 in hydrogen. The normal cathode fall remains practically constant as the current is increased, until a time comes when the glow covers the whole cathode. If, after this, the current is raised any higher the fall is said to be in the abnormal state and may rise to several hundred volts. Tubes are generally designed to run at, or only slightly above, the normal cathode fall.

The following is a table of the volt drop per foot run, for pure neon gas:

R.M.S. volts per foot for a diameter of tube of 15 mm.—Neon.

Current mA.	6mm. pressure	12 mm. pressure.
25	147	159
35	134	144
45	126	135

With the information in this table and a knowledge of the cathode fall—we may calculate the volt drop over the tube. Thus, take iron electrodes with 180 volts cathode fall used in a 10 foot long tube running at 35 milliamps with a pressure of 6 mms. of neon. The volt drop would be (134 × 10) + 180 = 1,520 volts.

A glance at the table shows that, as the current through the discharge increases, the volts across the tube go down. This is naturally unfortunate because there is nothing to prevent the current rising to catastrophic values unless the current is automatically limited by some external agency. This negative resistance effect is similar to that shown by the arc lamp.

The next important point to note is that the voltage required to start a discharge is greater than that required to maintain it. In the example we

have just considered, in which a little over 1,500 volts is required to run the discharge when once started, somewhere about 5,000 volts R.M.S. are needed to start the discharge. It is obvious that a tube designed to run at 1,500 volts would pass hundreds of amperes if 5,000 volts were permanently applied to it. The automatic limitation of the current can be achieved by using a choke coil in the primary of the transformer, or better, by designing transformers with magnetic leakage, so that the voltage automatically drops as soon as the tube strikes up and the discharge begins to pass.

FACTORS AFFECTING THE LIFE OF TUBES.

We must now consider more carefully the phenomena in the immediate neighbourhood of the cathode and their influence on the behaviour and design of discharge tubes. As already stated, this largely determines the life of a tube for the following reasons.

During the passage of a discharge a phenomenon known as cathodic sputtering takes place, which is the more vigorous the higher the cathode fall. This is something akin to evaporation, only instead of being due to the metal being at a high temperature it is produced by the impact of positively charged gas ions at the surface of the cathode. After a time this results in the formation of a film of metal on the glass walls surrounding the cathode, and, as the molecules of this film attach themselves to the glass they entrap gas atoms in the process. As the film grows it is therefore clear that the gas gradually disappears and the pressure inside the tube will decrease. We saw just now that once the pressure has fallen below one or two mm. the volts per foot will rise very rapidly until the discharge will no longer pass.

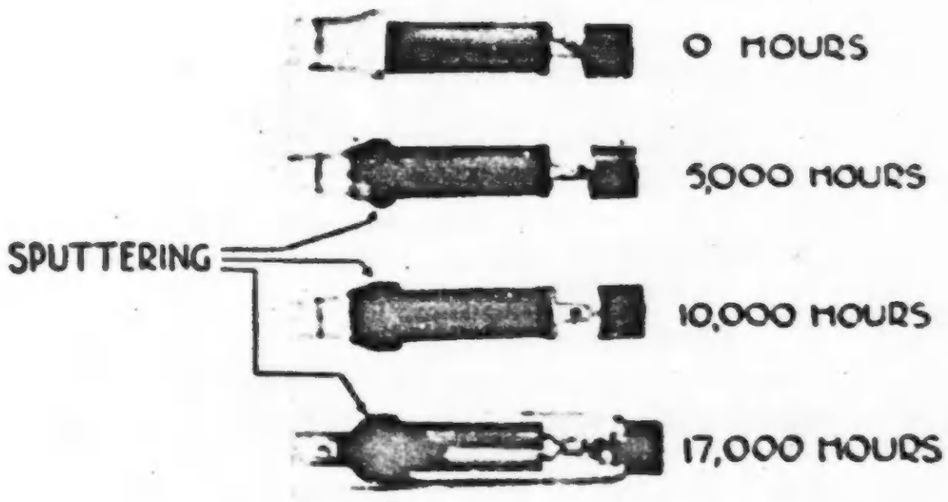

Fig. 10.—Appearance due to sputtering at various stages of life.

The rate at which this film is formed depends upon the current density at the cathode, so that for any given electrode size there will be a corresponding value of the current at which the tube will give a reasonable life.

How is the light output from the tubes influenced? The luminous efficiency is low at high pressures of gas. As the pressure is reduced the efficiency increases until a maximum is reached, after which it falls off very rapidly. The pressure for maximum efficiency depends on various factors—but with neon it is round about half a millimetre of mercury.

Naturally one would wish to work as near this pressure as possible, but considerations of the sputtering, which increases very rapidly as the pressure decreases, forces the use of higher pressures than this. In advertisement sign tubes, when very long lengths are required, pressures of several millimetres of mercury are generally used.

So far as concerns the total light given by a tube, it may be said roughly that in the case of neon, for example, the candle power increases proportionally to the energy dissipated in the discharge itself. Since the voltage across the tube decreases slightly with increasing current, it follows that as the current is increased the resulting light is not quite so great as would be expected if it was strictly proportional to the current.

HOT CATHODE TUBES.

The discharge tubes which we have been considering up to now, although ideal for advertisement signs where we want to see the long sources of light themselves, are not of so much value for general illumination purposes, where we usually hide the source of light itself and allow its rays to illuminate and reveal the surrounding objects. This is firstly because these tubes require high voltages and secondly because of the relatively small amount of light which they yield per foot of tube. This means that for street lighting or flood lighting, an inconvenient length would be required to afford adequate illumination. Nevertheless, the old Moore tubes were used in long lengths for interior lighting, and similar tubes are indeed of real value for producing special effects. But at present we do not know how to employ them economically where concentration of the light is needed by means of optical systems. You will remind me that the object of good street lighting is to keep down the brightness of the sources themselves—and long lengths of these low brilliancy tubes should therefore yield an attractive and efficient street lighting system. However, a way of employing them effectively and efficiently for this purpose has yet to be developed.

Clearly what is needed for these purposes is a tube which will give 10 or 100 times the light output per foot run. Now the light increases as the current increases, but we cannot increase the current in cold cathode tubes without shortening the life of the tube owing to sputtering—unless we do it by increasing the area of the electrodes. But to do this effectively we should need electrodes one hundred times the

area of the present ones—which is out of the question.

If we could pass a heavy current without increasing the size of the electrodes we should solve both our difficulties at one stroke, because, as we have already seen, the volt drop per foot will be greatly reduced—and the shorter length would enable us to use lower voltages.

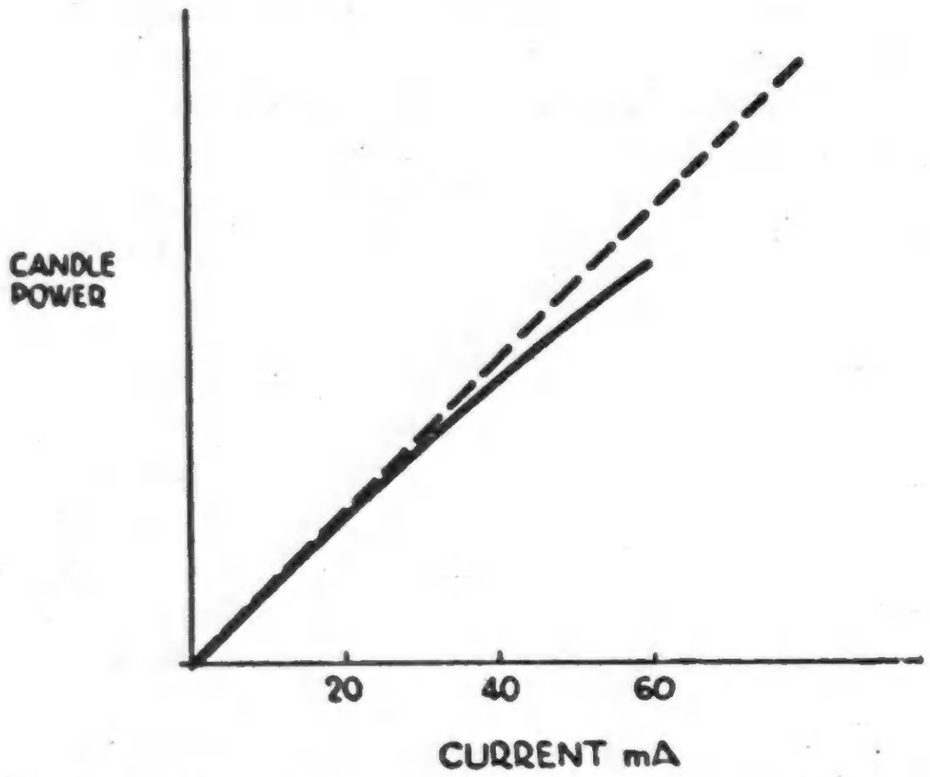

Fig. 11. Variation of candle power with current through the tube.

The solution which was put forward by Pirani in Berlin and by the General Electric Company of America consists in the application of the well known fact that if the cathode is heated to a temperature at which it will emit electrons freely, then the cathode fall will be greatly reduced, and large currents passed without serious sputtering taking place.

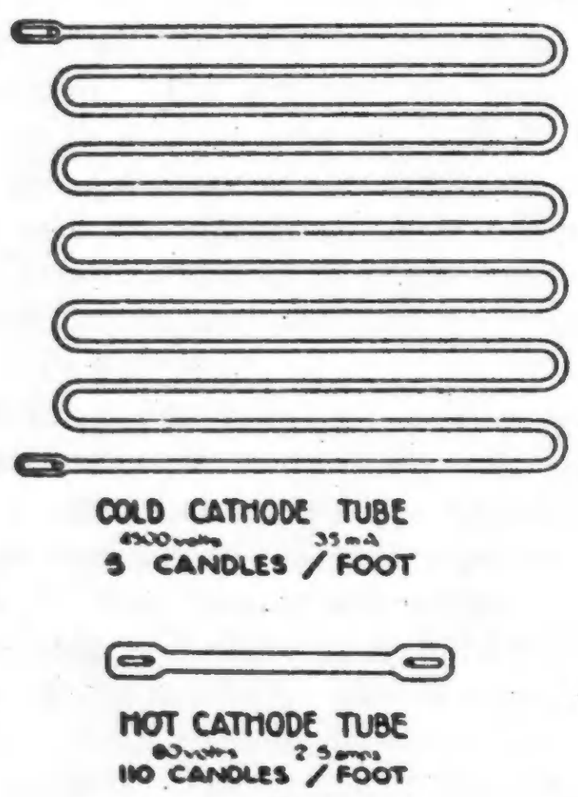

Fig. 12.—Cold and hot cathode tubes of equal candle power.

Tubes embodying these principles form a new and separate class which we will call hot cathode. What now follows will mainly concern tubes of this type. Amongst them are to be found some of the latest and most interesting developments.

In them the electrodes consist of alkaline earth oxides which can be heated electrically like small filaments. Alternatively they may be formed of small oxide-coated metal cylinders which can be indirectly heated by a tungsten spiral inside, much as the cathodes in indirectly heated cathode valves. By the use of these electrodes the cathode fall is greatly reduced and is, in fact, only about 25 to 30 volts. As a result of this, much larger currents can be passed without appreciable sputtering taking place. In fact, the current can be increased some

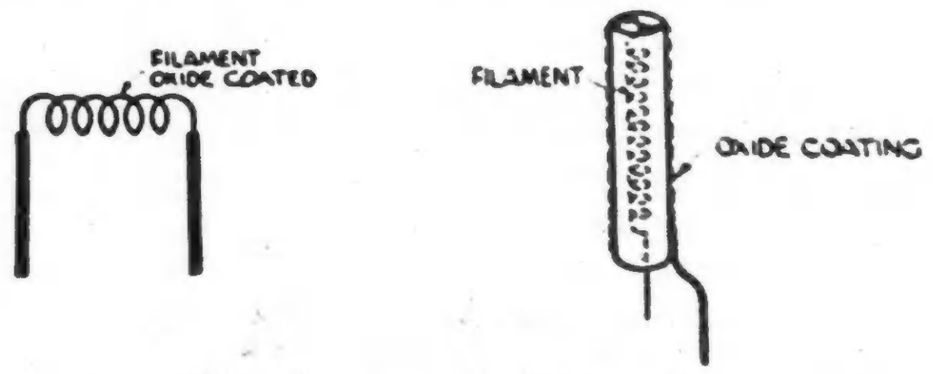

Fig. 13. Hot cathode electrodes.

30 or even 100 times that which would be possible with ordinary cold cathodes. The current is now only limited by the heat developed by the discharge which, if excessive would soften the glass walls. As a result of the high current, the voltage drop per foot of the positive column is now much less than in the case of the cold cathode tubes; also, as already stated, the cathode fall is greatly reduced. In consequence the running voltage is so small that the discharge can be maintained on the ordinary supply voltages, and no step-up transformer is

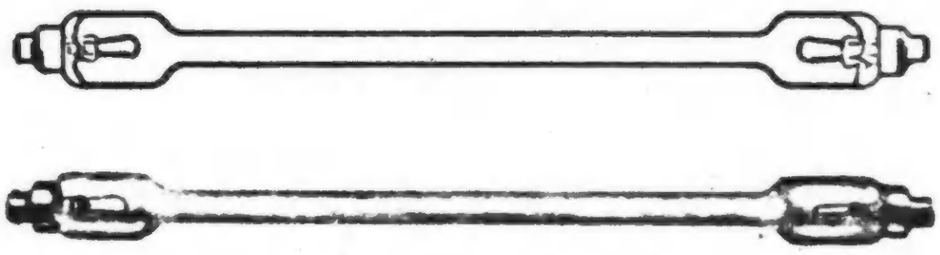

Fig. 14.—Hot cathode tube.

needed. A choke to limit the current is, however, necessary and a small filament heating transformer to supply current for the electrodes. The starting potential of these tubes is still rather high, and so it is generally necessary to supply a momentary high voltage to start the discharge. This is most easily done by means of a small high frequency Tesla coil.

THE GAS.

From what gases or vapours are we free to choose for use in discharge tubes?

Firstly, the gas must, when excited by the discharge, emit a suitable spectrum. We must remember that the light we see is not the whole of the radiation that is emitted by the gas. There are the ultra-

violet and infra red regions to which some gases devote a great deal of their radiant energy. Such gases are of little use for efficient light sources, though some may be used occasionally if special colours are desired. One example is carbon dioxide which, although not efficient, gives a fine white light, very similar to daylight; another is hydrogen which gives a beautiful pink colour but is extremely inefficient as a producer of light.

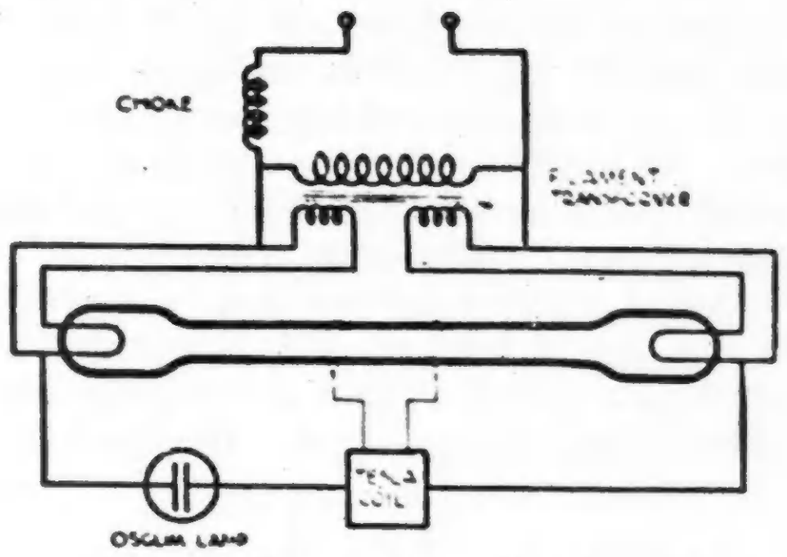

Fig. 15.—Hot cathode tube circuit.

Secondly, the gas or vapour must not decompose under the action of the discharge. For example, hydrogen sulphide does so and when it breaks down, sulphur is deposited on the glass walls.

Thirdly, the gas must not attack the glass or electrodes. For this reason fluorine or chlorine gas would be quite unsuitable.

Fourthly, when using a *vapour*—as distinct from a gas—as the main constituent, the vapour pressure

Some gases and vapours which might be used in discharge tubes

HYDROGEN	HELIUM	LITHIUM	CALCIUM	MAGNESIUM
NITROGEN	NEON	SODIUM	STRONTIUM	ZINC
OXYGEN	ARGON	POTASSIUM	BARIUM	CADMIUM
	KRYPTON	RUBIDIUM		MERCURY
	XENON	CAESIUM		
		ELEMENT 87		

GALLIUM	PHOSPHORUS	SULPHUR	FLUORINE
INDIUM	ARSENIC	SELENIUM	CHLORINE
THALLIUM	ANTIMONY	TELLURIUM	BROMINE
	BISMUTH		IODINE

Also compounds e.g.
CARBON MONOXIDE
CARBON DIOXIDE
CYANOGEN
SULPHUR DIOXIDE

Fig. 16.—Table of gases and vapours which might be used in discharge tubes.

must be appreciable (several tenths of a millimetre) at temperatures below the softening point of the glass. Thus the vapour of tin or boron would never do.

Fifthly, the colour of the glow, either alone or combined with that of other tubes, must be useful. We have already seen that most gases or vapours when under the influence of the discharge, emit radiation in a few limited regions of the spectrum only. In this they differ radically from the incandescent tungsten filament lamp which emits all wavelengths of the visible spectrum. Thus sodium vapour emits much the greatest part of its light at a wavelength of about 5,890 in the yellow region and only a minute amount in the green and blue regions. Sodium vapour alone is therefore likely to be limited in its use for general lighting, because the only colour it appears to call into existence in the objects it illuminates is yellow. The molecules in the objects to be seen, which would ordinarily reflect in the blue and green wavelengths, are not suitably stimulated by sodium light and the eye therefore misses the blue and green sensations. If, therefore, sodium is to be used at all generally in discharge tubes it should be in conjunction with some other gas which will add to the sodium radiation other wavelengths—the sum total of which will give reasonably good colour rendering.

Sixthly, the voltage to strike the tube when starting up, varies greatly with different gases. It is desirable that both this starting voltage as well as the running voltage should be low.

Lastly, the gas should not clean up easily on to the glass walls under the action of the discharge, otherwise we shall experience the same trouble as occurred with the original Moore tubes which had to have a more or less elaborate replenishing device for introducing fresh gas to make up for that which had become immobilised on the glass walls of the electrode chambers.

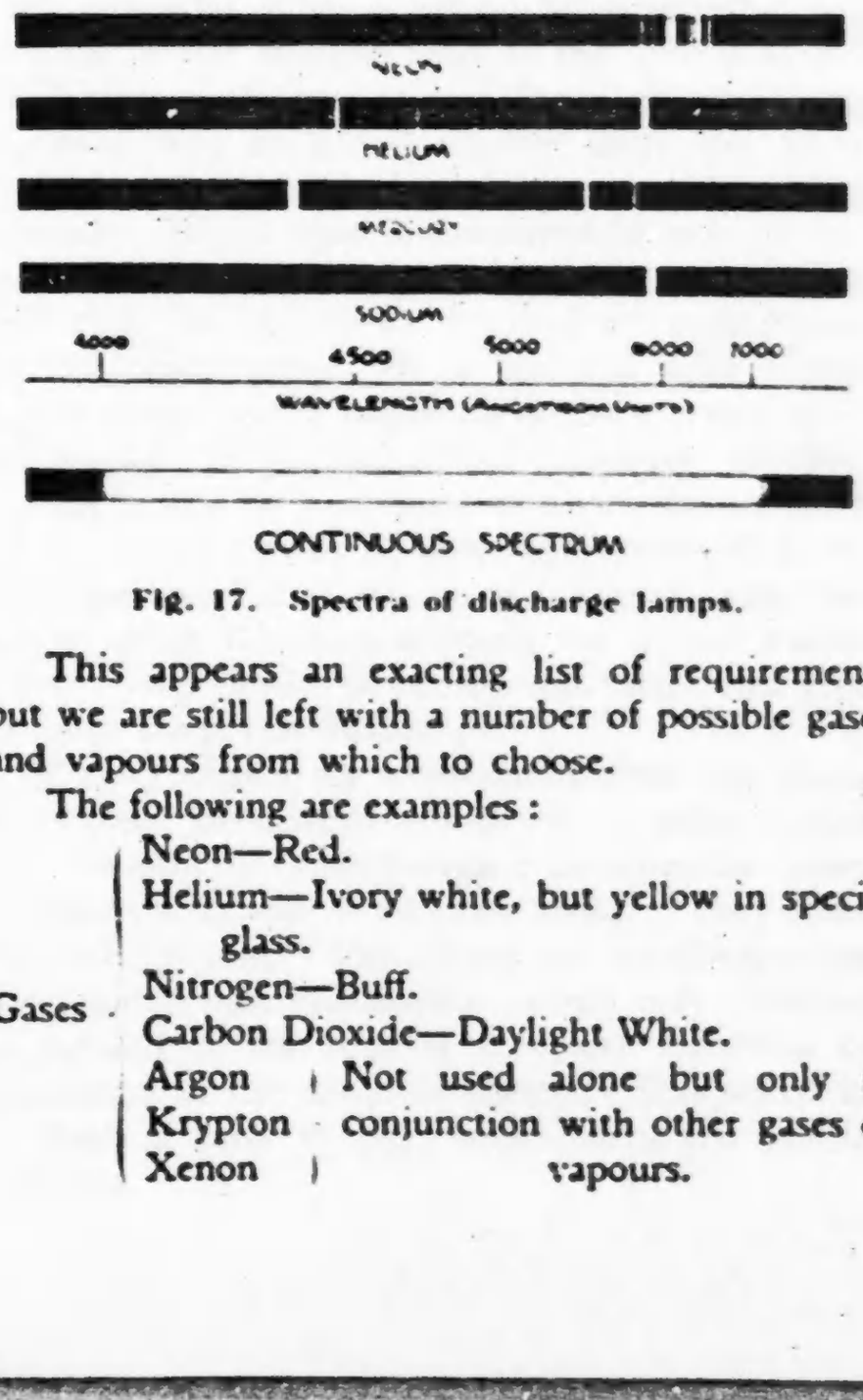

Fig. 17. Spectra of discharge lamps.

This appears an exacting list of requirements but we are still left with a number of possible gases and vapours from which to choose.

The following are examples:

Gases
- Neon—Red.
- Helium—Ivory white, but yellow in special glass.
- Nitrogen—Buff.
- Carbon Dioxide—Daylight White.
- Argon, Krypton, Xenon—Not used alone but only in conjunction with other gases or vapours.

Vapours	Mercury	Blue to white according to pressure.
		Green in special glass.
	Sodium—Yellow.	
	Cadmium—Greenish Blue.	
	Thallium—Green.	
	Magnesium—Grass green.	

A white light can be obtained from a neon tube in which a little mercury vapour is present—provided that just the correct quantity is maintained.

It will naturally be asked why cannot any desired hue of light be obtained by mixing in one tube any of these gases and vapours in the right proportions? Unfortunately the matter is not so simple as this. As already stated, each gas requires a unique value of voltage to stimulate it. If several gases or vapours are present in a tube together, in general, that requiring the lowest voltage to stimulate it will mask those which require high voltages to stimulate them—unless indeed their voltages have closely the same value. Thus the characteristic colour of the gas requiring the lowest voltage to stimulate it will dominate the hue of the radiation.

For instance it would seem to be a very attractive idea to use a mixture of sodium, mercury and neon in the same tube and combine their yellow, green, blue and red spectrum lines to obtain a good radiation. But for the reason given these will not work together in harness as we want them to. The willing horse does all the work.

This applies specially to the positive column. Near the cathode it frequently happens that when more than one gas is present, the characteristic colour of that requiring the higher ionisation voltage will show up, although it is masked in other parts of the tube. If we think for a moment we can see the reason for this. The gas with the higher excitation voltage can be excited near the cathode because the cathode fall of voltage takes place over a very short distance, and the speeds of the electrons here are higher. Thus for mixtures, a gas can be excited in the cathode fall region which in the positive column remains relatively inert.

In what has just been said we have assumed that plenty of each gas is present. If, however, we consider a tube containing a gas, together with such a metal as mercury which will evaporate as the tube gets hot, we find that at low temperatures the gas spectrum only will show, and at high temperatures only that of the mercury. But at some intermediate temperature both the gas and the vapour of mercury will be excited. The practical difficulty is to hold the temperature conditions in such a state of equilibrium that the radiation of both elements remains steady in the desired amounts.

POWER FACTOR.

Owing to the fact that the gas discharge does not obey Ohm's law, the wave form of the current or of the voltage across the tube is not a simple sine curve. Fig. 18 shows some typical oscillograms. In the case of a neon cold cathode tube it will be noticed that at the beginning of each cycle the voltage rises up to the value at which the discharge strikes and then it rapidly falls to a steady value, finally dropping sharply to zero at the end of the half cycle. Looking now at the oscillogram of the current, this of course remains zero until the voltage has risen to the striking value and then it rises, but only to fall to zero again just before the end of the half period. In the case of the mercury tube you will notice that the first peak is almost absent owing to the fact that the striking voltage is much nearer to the running voltage than in the case of neon. The oscillograms for hot cathode tubes are much the same, but the peak with neon is generally not so pronounced. The exact wave form depends on the type of tube and on the circuit conditions. How does this wave form affect the power factor?

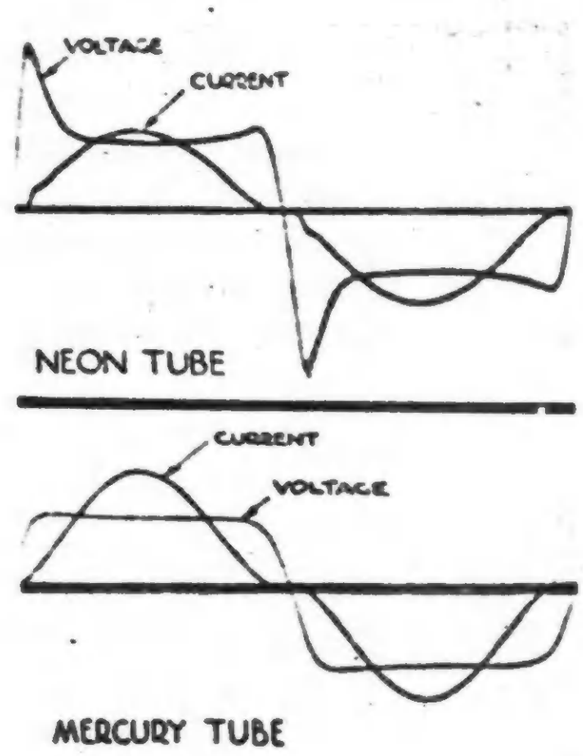

Fig. 18—Oscillograms of discharge tubes.

If a supply voltage is applied to a simple circuit consisting of an inductance and capacity, the product of the current and voltage multiplied by the power factor gives, as everyone knows, the true watts dissipated in the circuit. When the applied voltage is sinusoidal, the power factor is readily calculated in terms of the values of the inductance and capacity and it becomes unity when these values are zero, or bear a certain definite relation to one another. But if the sinusoidal potential is applied to a circuit not obeying Ohm's law then the power factor will not be unity, even if no inductance or capacity is in the circuit.

Engineers in the past became so accustomed to being able to assume that their wave forms were sinusoidal and their loads, for practical purposes, ordinary inductances or capacities that the power

factor b came synonymous with Cos ϕ—the cosine of the angle by which the current lagged behind the voltage. They were apt to forget that the sinusoidal wave was only a very special case in the whole power factor problem. With discharge tubes, whilst we can and do use condensers to eliminate the current lag caused by the series choke and thereby cause the beginning and the end of each current half cycle to coincide with the beginning and end of its voltage half cycle, yet owing to the considerable wave form distortion produced by the discharge, the power factor will still be less than unity. Hence, as we add capacity to our circuit the power factor improves up to a point, but then as we add more it begins to drop back again without reaching unity. It turns out in practice that a power factor of at least 0.8 can readily be obtained in this way with cold cathode tubes running on leakage transformers. With hot cathode tubes the same applies and, in

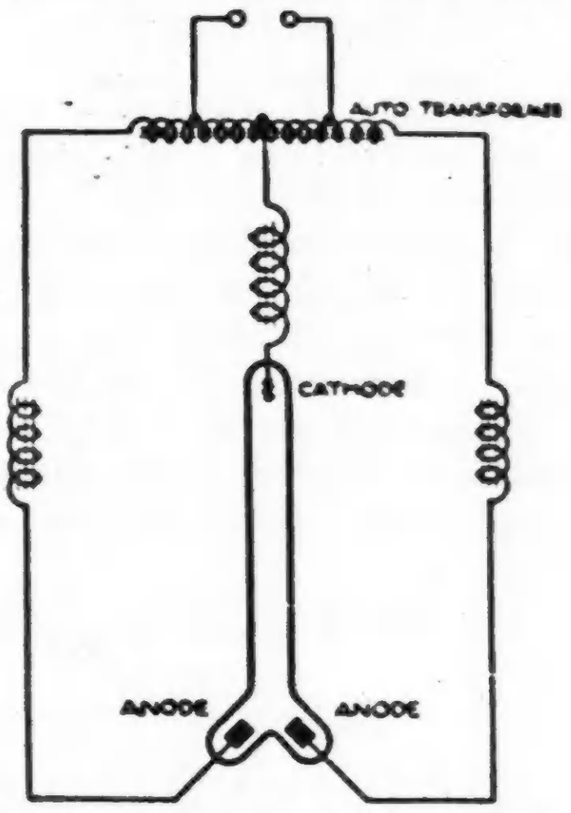

Fig. 19.—Circuit for double anode tube.

fact, even better correction (0.95 for example) can be achieved with some of the more important new types.

SUCCESSIVE IMAGE EFFECT.

We hardly notice the 50 cycle alternations of supply voltage when applied to an ordinary incandescent lamp because the filament does not seriously cool down between successive half cycles. On the other hand, gas discharge tubes follow the current changes more closely and therefore the "successive image" effect of moving objects is more marked, and is sometimes a nuisance when objects are moving rapidly.

If a three phase supply is available this effect can be practically eliminated by running nearby tubes on alternate phases. This, however, is not generally feasible so that we have to consider what other means is available.

Suppose we construct the tube with two anodes at one end and a cathode at the other and connect it up as shown in fig. 19. It is easily seen that current will flow through the tube in the same direction at each half cycle, but first through one half of the circuit and then through the other. The effect of the inductance in the circuit is to cause the current half cycles to overlap, and if its value is high enough it will practically eliminate the successive image effect. The only disadvantage of this system is that it needs so much gear for each tube.

The effect is one which must be reckoned with. My impression is that it is not so troublesome as the so called "flicker" effect on 25 cycle supplies with ordinary lamps—but only experience under all conditions will settle this.

PHOTOMETRY.

Complications of a serious kind arise when we try to think of the luminous output of coloured discharge tubes in terms of candle power—for the standards of candle power we use for comparison give white—not coloured—light.

Some very broad issues arise here. There are those who claim that even when we have achieved, on the basis of the laws of physics, an accurate comparison of our coloured discharge lamps with our candle power standards, the result is not a true gauge of the effectiveness of these light sources to aid human vision in discriminating objects. It is suggested that physiologically one colour is better than another for seeing with, and particularly that if the coloured light is monochromatic—that is, restricted to one narrow band of the spectrum, the optical system of the eye can focus objects more accurately, and so get effectively more out of a candle than if the light source emits over the whole spectrum. Whilst this is undoubtedly true in the discrimination of fine detail—there has yet been no proof that we should be justified in multiplying physical candle power by a coloured light factor to turn them into a higher or a lower value of—shall we say—"Physiological" or "Effective" candles.

This would be equivalent to saying for instance that 50 candle power of neon light is equal to 65 candle power of daylight, or of tungsten light, and that we must therefore multiply up all our values of neon lamp candle power by this factor and give the neon lamp this advantage.

If such claims for monochromatism are made they should be discounted—if for no other reason than that strictly monochromatic illumination causes all objects to appear of the same colour. They differ only in brightness. The alleged greater effectiveness of discharge tube illumination would only therefore be secured at the cost of complete distortion or elimination of the colour of objects. This would be too high a price to pay, except in a few special instances.

The basis of measurement of candle power of these coloured sources in terms of our ordinary units is not yet established. For good or for ill the past has bequeathed to us a unit of light intensity based on sources which produce a continuous spectrum. Hitherto our sources of light, whether the sun or incandescent solids emit light of all colours; the various sources differing, in that the proportions of light of the different colours are not equal.

Whilst it is true that these differences introduce certain difficulties when it is desired to compare the light-giving power of two such sources, to a high

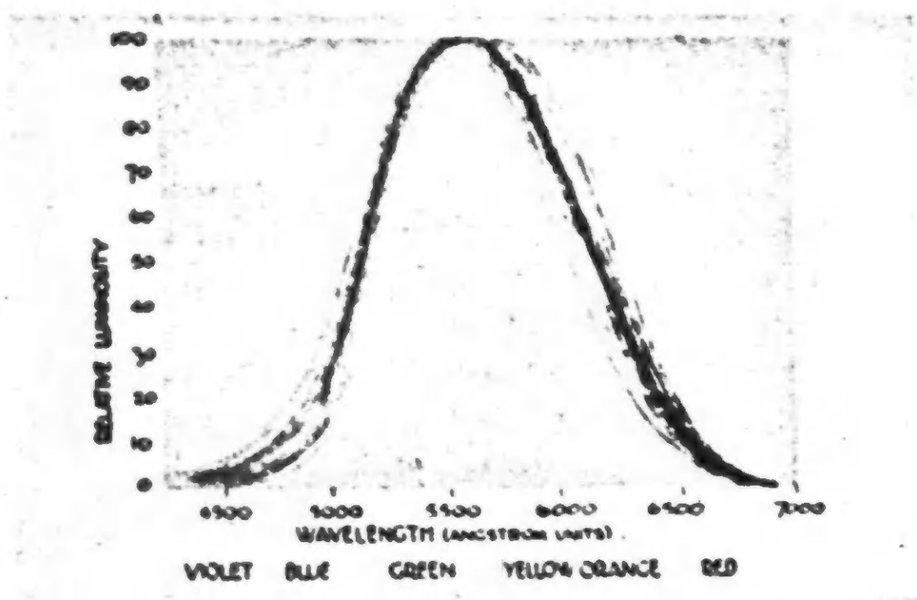

Fig. 20.—Relative luminosity curves (125 persons).

accuracy, yet no very serious difficulty is in general encountered by the individual observer.

Before passing on to consider the evaluation of the light-giving power of discharge lamps which only emit light of one or two colours, let us first examine a little in detail what is involved in making these measurements.

In fig. 20* is shown a mass of curves each one of which represents for one observer the brightness which a white surface would appear to have when a constant amount of radiant energy of different wavelengths falls upon the surface. Not only does the colour of the surface appear to change as the wavelength or frequency of the radiation changes, but also its brightness. The vertical ordinate of each of these curves at any point is proportional to the apparent brightness of the surface to one observer.

You will see how different these curves are liable to be for different observers by noting the spread on any vertical ordinate.

To compare the light emitting powers of two incandescent bodies (say carbon filament and tungsten filament or two tungsten filaments at different temperatures) which differ in the proportion of light of different colours emitted, three methods are often employed, which in general yield a different result for any particular observer and also different results for different observers.

The methods are:

(*a*) The direct contrast method where two parts of a surface in juxtaposition are viewed simultaneously and the distances of the sources from the surface adjusted till both parts appear equally bright.

(*b*) The flicker method where the two sources illuminate two parts of a surface which are viewed in rapid succession; the position of the sources is adjusted until the flickering effect produced is reduced to a minimum.

(*c*) The filter method (using spectrophotometer).

In this method a filter is chosen which, when placed in front of a standard source modifies the colour of the light in such a way that it appears to have the same colour as the other source whose candle power is unknown.

In order to find the candle power of the standard source modified by the filter, the following steps are necessary. The transmission of the filter for each wavelength is measured on a spectrophotometer, an instrument by which the contrast method of measurement is carried out without colour difference.

The next step is to determine for the standard source the relative amount of energy it radiates in each wavelength.

Lastly, the relative luminosity of the radiation averaged for a large number of observers for the different wavelengths is obtained. (This is determined from data illustrated by fig. 20).

This long series of observations is then utilised as follows:

Wave-length A.U.	Filter trans-mission.	Relative Energy.	Relative Lumin-osity. (Visibility)	Product of Cols. 2, 3 and 4.	Product of Cols. 3 and 4.
Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6
4000	.52	0.77	.004	.0016	.0031
4200	.54	1.18	.040	.0255	.0472
4400	.57	1.71	.230	.2242	.3933
—	—	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—
				Sum X	Sum Y
Filter Transmission				X / Y	

The sum of the products given in Columns 5 and 6 are then determined and the ratio of the sum of Column 5 to the sum of Column 6 gives the transmission factor of the filter for the composite light of the standard source, and for the hypothetical average eye. Then the candle power of the standard source combined with the filter is obtained from the known candle power of the standard source above, multiplied by the transmission factor of the filter just determined. Then this combination of standard source and filter can be used as a new standard of closely the same colour as the unknown source, to measure the candle power of the latter by the ordinary methods.

*Reproduced from Coblentz & Emerson, Bull. Bureau Stds. Vol. 14, p.206 (1918)

These three methods when used in photometric laboratories of the highest class, utilising the most refined methods, have not yielded agreement better than ± 2.0 per cent when comparing a carbon lamp with a tungsten lamp.

Now when attempting to measure a sodium or neon discharge lamp the difficulties outlined above become very much enhanced. However, in principle the same procedure has to be adopted.

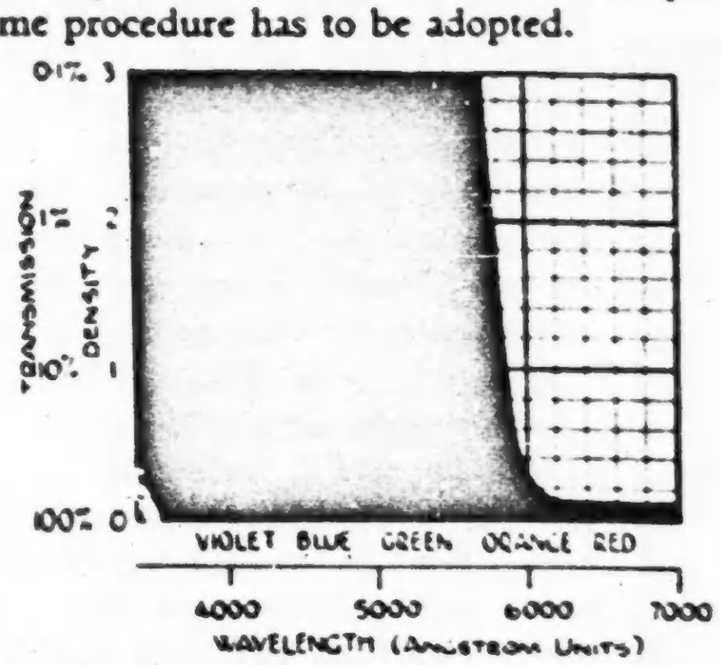

Fig. 21.—Transmission curve of filter used over tungsten lamp to produce approximate neon colour.

The properties of the filter chosen to modify the light from a tungsten lamp so that it closely matches the colour of a neon lamp are illustrated in fig. 21.

By determining the transmission factor of this filter for the light of the tungsten filament lamp by all three of the above methods, and then utilising this when making direct comparisons between

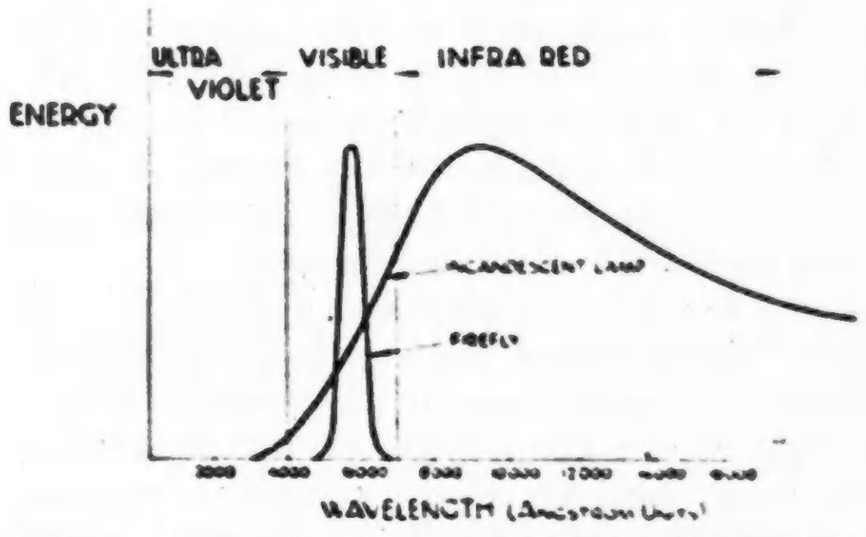

Fig. 22.—Energy distribution of firefly and incandescent lamp.

tungsten and neon lamps, a reasonable approximation to the candle power of the neon lamp can be made.

FACTORS AFFECTING EFFICIENCY.

A word now on the subject of the efficiency of discharge tubes. We must think of this as influenced first by external and then by internal factors. The external factors are the losses in the series reactance, which is introduced to counteract the negative resistance of the tube. Also there are very small losses in the condensers used to correct the power factor. These electrical losses are of course obvious to every electrical engineer. The internal factors which influence the efficiency are much more numerous and complex. Some gases and vapours are intrinsically more efficient as light sources than others, not only because they emit radiation at wavelengths lying in the parts of the visible spectrum to which the eye is most sensitive, but also because they emit comparatively little outside this range. A source which emits most of the energy in the visible region will naturally have a greater luminous efficiency than one which emits a considerable amount of infra red or ultra violet radiation. The fire fly, for example, emits a continuous spectrum but practically the whole of it lies between the green and the red limit of the spectrum. The maximum emission is

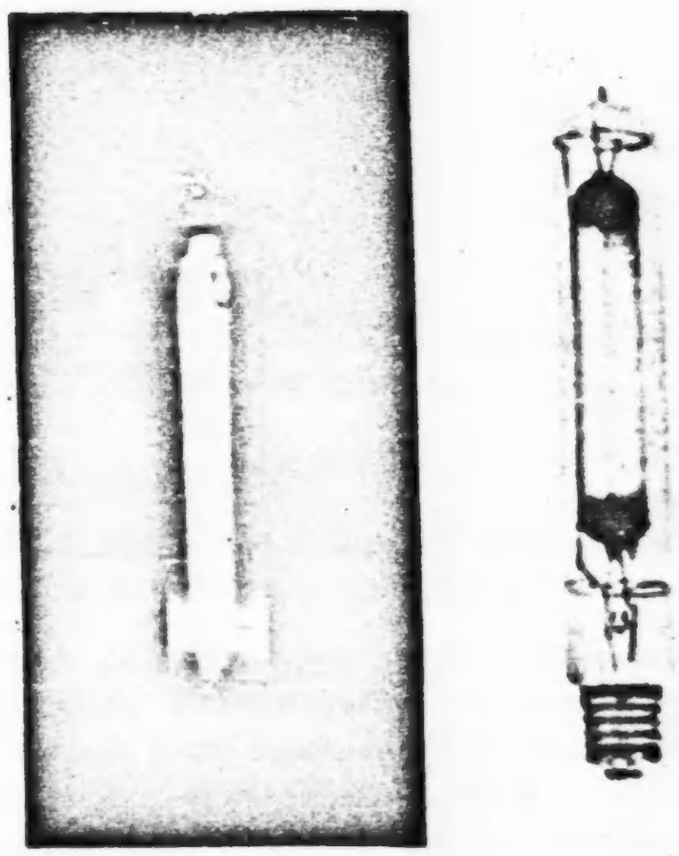

Fig. 23.—New G.E.C. "Wembley" lamp.

in the yellow green at 5,700A. If you compare the energy distribution for the fire fly and for an ordinary lamp, as shown in fig. 22, you will see the very large proportion of the energy which is emitted in the infra red by the lamp. The fire fly, on the other hand, restricts its radiation to the visible spectrum and in consequence is an extremely efficient light source.

It is, however, a very feeble one; about 1,600 fire flies all glowing at the same time would be required to give one candle power.

In the case of excited gases we have seen that, instead of continuous spectra, they emit radiation of certain wavelengths only. If all the energy supplied to a discharge tube were emitted at a wavelength of 5,550A., corresponding to the peak of the relative luminosity curve of the eye, the luminous efficiency would be in the neighbourhood of 670 lumens per watt, compared with that of a 100 watt incandescent lamp with an efficiency of only 12 lumens per watt. 92 per cent of the energy supplied to the incandescent lamp is radiated in the non-luminous portions of the spectrum. For reasons which we need not review

now, this considerable waste in the infra red is inevitable so long as the source of light is a hot body such, for example, as the filament of a lamp.

Let us now examine the radiation from one of these excited gases, taking a sodium lamp as the example. We find that, when it is burning under normal conditions, the energy emitted as infra red lines is only about one quarter of that emitted as the yellow D lines, as shown in fig. 8. The energy corresponding to the remaining lines in the visible and ultra violet regions only amounts to a few per cent. Now from the visibility curve we find that sodium yellow light of wavelength 5,890A. is about 78 per cent as luminous as the green light corresponding to the peak at 5,550A. Taking all these factors into consideration we might expect a very high luminous efficiency, somewhere about 360 lumens per watt. This has in fact been achieved at low intensities and under artificial conditions by Pirani, but it cannot be done practically. In practice it is, however, now possible to make 100 watt sodium lamps to have an efficiency of 70 lumens per watt, a great increase over the 12 lumens per watt of the corresponding incandescent lamp! But what is to account for the difference between the theoretical 360 and the practical 70 lumens per watt? The answer is that so far, we have neglected all the losses in the tube itself. To understand these we must return to our discussion of the atomic processes going on in our tube. You will remember that when an electron flying through the gas collides with an atom, one of two things may happen. If its velocity is below a certain amount, the collision is elastic, while if it is greater than the critical value the atom is excited and may subsequently emit radiation. Previously we have studied the second of these processes, but what of the first? The electrons in an actual discharge tube are moving very fast and the result of all the elastic collisions is to speed up the atoms of the gas. The average velocity of the atoms in a gas is, of course, a gauge of its temperature, so that the result of the elastic collisions is that the gas gets hot. The gas, in turn, heats up the walls of the tube and this finally radiates in the infra red region. There are many other more complicated processes going on at the same time but all end in the one way; valuable electrical energy is finally turned into heat at the glass walls and thus lost. One would therefore be inclined to say that what we want is a set of conditions under which no elastic collisions take place and none of these other wasteful processes occur. This is more or less desirable in the case of gases but with some vapours, sodium in particular, it is not so. At room temperatures, hardly any sodium would exist in the tube as vapour, so that in order to vaporise the required quantity, the tube must be kept hot. In order to obtain a highly efficient sodium tube it has to be lagged by surrounding it with an evacuated outer jacket to retain the heat; at the same time the elastic collisions and the other wasteful processes must be reduced. The most efficient tube will then be one in which the lagging is the greatest possible, and the heat producing processes are reduced to the minimum required to maintain the inner tube at the required temperature. If this be chosen too low, there will be insufficient sodium atoms present, while if it be too high the efficiency will drop because a greater proportion of the input energy is used up in the heat producing processes.

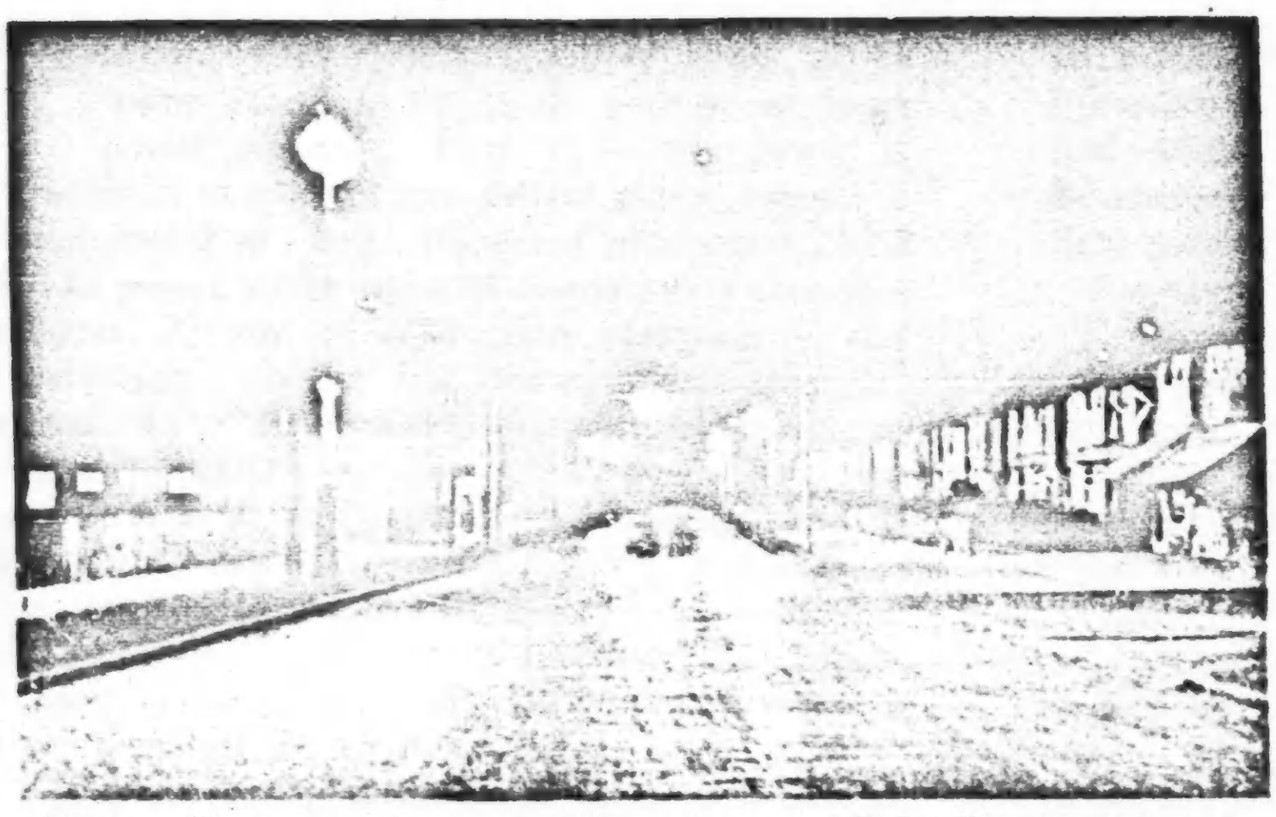

Fig. 24. Discharge tube street lighting by new G.E.C. "Wembley" lamps.

This is a relatively simple case. With other vapours such, for example, as mercury, other factors, some of them extremely important, must be considered. But an attempt to deal with these here would lead us now into too great detail.

RECENT DEVELOPMENTS.

As you will recognise, the development of hot cathode tubes has proceeded very quickly during the last year or so, and many types are now rapidly approaching a commercial stage. Let us briefly review some of the lamps and units which have reached various stages of development. If some particulars have to be omitted it is because it is difficult to discuss technical developments which are incomplete and not as yet properly incorporated in commercial products.

First of all, by placing neon and mercury tubes (the latter in either clear or green glass) in parabolic reflectors, very effective units are obtained suitable

for the colour floodlighting of buildings, and the like. The efficiency of these is very greatly in excess of the ordinary incandescent lamps when combined with the colour filters which at present have to be used for this purpose. Then, by combining a neon and a mercury tube, the latter in a special fluorescent glass, a unit is obtained which emits a very pleasant light giving good colour rendering of objects. In this unit the tubes are enclosed behind opal glass sheets which mix and diffuse the light. Another development is the combination of hot cathode tubes with incandescent lamps. Neon tubes in this case tint the light and give it a rosy hue, blue mercury tubes give a daylight effect and also supply ultra violet light, if required. The advantage of this combination is that the incandescent lamps not only give useful light but owing to their being in series with the discharge tubes, they act in place of choke coils.

Secondly, we come to a very interesting new type of tube which has recently been developed at the G.E.C. Laboratories at Wembley. It is made at the moment in 400 watt units. This type, which is beginning to emerge from its experimental stage, consists of a vertical tube in which the discharge takes the form of an extremely brilliant narrow cord of light about 6 inches high. The efficiency of a 400 watt lamp of this type is at present about 40 lumens per watt (as compared with 15 lumens per watt for a corresponding tungsten lamp), but higher values than this have been obtained in experimental tubes. The light from this lamp is deficient in red but, if combined for instance with a neon tube, much better colour rendering would be obtained. It would seem that, when fully developed, this type of lamp should be particularly suitable for lighting streets and important thoroughfares. The street outside the Laboratories is at present illuminated entirely by these lamps in which, however, the colour is not yet corrected. The effect is striking though not yet as good as future developments can make it. This Wembley installation was first run at the beginning of July, 1932.

Thirdly there is the sodium lamp, which emits practically only a pure yellow light. This type of lamp was first developed by Pirani of the Osram Company, Berlin, whose researches showed how a glass could be made to withstand the attack of hot sodium vapour throughout hundreds of hours. A similar lamp of modified construction has also recently been developed by the Philips Company in Holland. There is an excellent section of road lighted with these in Holland and another in Zurich. The practical applications of the sodium tube have been specially studied by the Germans and the Dutch. The author showed early examples of sodium lamps two years ago at the Institution of Electrical Engineers—and further types have been under development. A type developed by Pirani,

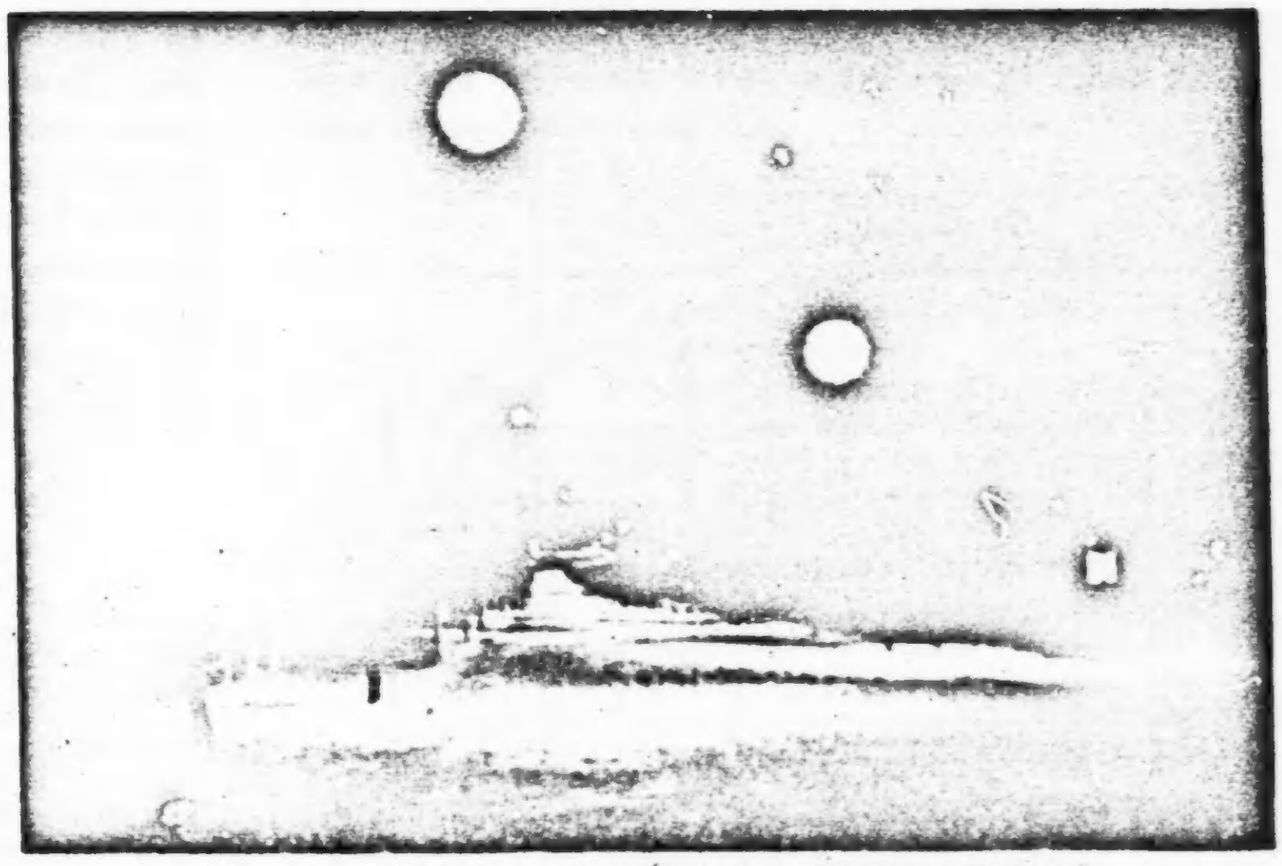

Fig. 25. Discharge tube lighting by Phillips, Holland.

of which examples have recently been constructed at Wembley already yields 70 lumens per watt. The sodium lamp lends itself to small wattage sizes of 80 to 150 watts, but in view of the extreme colour distortion produced by the sodium lamp it is not very suitable at present for general lighting or even for lighting ordinary streets. It is however, being tried for lighting stretches of arterial and country roads where the lack of good colour discrimination is of little importance and where the illumination is nearer those lower levels at which the eye in any case is not accustomed to distinguish colour. In other words, if the illumination is so low that the cones of the retina are out of action and we are using only rod vision—it does not so much matter if the light is monochromatic.

As for the future, who would care to predict what possibilities lie in store for us, after we have seen the rapid progress which has taken place in this fascinating field during the last year? But of this one can feel sure—once these new tubes reach the commercial stage, the next developments must proceed along the lines of improving first the colour and then, still further, the efficiency. Furthermore, much effort will have to be spent on adapting the different types to the varied illumination requirements of street and building. Meanwhile we may be confident that further fundamental research will reveal the possibilities of other new types of lamp—for many avenues still lie open to be explored.

Steam Turbines for Combined Supply of Power and Heating Steam.

By B. POCHOBRADSKY, M.I.Mech.E.

Chief Engineer, Fraser & Chalmers Engineering Works of The General Electric Co., Ltd.

PUBLIC electric power supply tends to be concentrated in a small number of large power stations; from these the power is transmitted to more or less distant places whence it is distributed to a large number of consumers. The cost of power at the point of consumption therefore includes the cost of production, transmission and distribution. As the first two operations are performed on a large scale, the cost of power is, generally speaking, smaller than if power had been generated in a large number of small stations and transmitted over a shorter distance. The bulk of this power is generated in this country and other coal-producing countries by means of condensing steam turbines, as this type of prime mover has given the most satisfactory results.

It is interesting to note that the overall thermal efficiency of large power stations equipped with steam turbines has reached about 24 per cent. This means that about 24 per cent of the potential heat of coal is transformed into useful electrical energy, the remaining 76 per cent escaping as loss to atmosphere (heat in flue gases, radiation and leakages) and to cooling water (through condensers, oil coolers and air coolers).

The overall thermal efficiency can be improved by increasing the steam pressure and temperature, by the adoption of interstage re-heating and other means. The extent of the possible improvement however, is small, and it can be assumed that about 26 per cent overall thermal efficiency will be a representative figure for large power stations for a number of years to come.

In many industries steam is used for process work such as drying and boiling, while in others and in large institutions, considerable quantities of steam are used for ordinary heating purposes. In the first category may be mentioned:

Paper and cellulose manufacture.
Spinning, weaving and dyeing.
Artificial silk manufacture.
Breweries and distilleries.
Leather and rubber industries.
Oil refineries.
Sugar, cocoa and sugar goods industries.
Manufacture of chemicals, fertilizers, dyes and drugs.
Gramophone records.
Potteries.
Furniture industries.
Laundries.
Manufacture of explosives.
Soap industry.
Etc., etc.

To the second category (steam for ordinary heating purposes) belong many large industrial plants, stores, hotels, hospitals, banks and the like.

In these establishments, while steam is used for process or heating purposes, power is required at the same time for lighting, lifts and driving machinery of all kinds. In all these instances this combined power and heating steam supply can be provided by special steam turbines of the back-pressure, passout-backpressure or passout type, and it is the purpose of this article to show the economic advantages obtained by installing turbines of this type where power generation and heating steam supplies are required.

BACKPRESSURE TURBINES.

Of the three types of turbine mentioned, the simplest is the backpressure turbine. Steam is led from the boilers to a backpressure turbine, in which part of the steam energy is utilised for power generation and the remaining heat is used for process work or heating, a very small percentage being lost. All the internal losses in the turbine re-appear as heat in the heating steam, the only losses being the very small radiation, bearing friction, leakage loss and power for driving the lubricating oil pump and governor. As there is no lubrication in the steam spaces of a turbine, the steam leaving the turbine is not contaminated by oil, a feature which is a great advantage in regard both to heat transmission and to the process work itself.

Assuming that the total useful output of such a turbine is made up of the power generated and the total heat delivered to the heating system, the overall thermal efficiency of the whole steam plant (consisting of boilers and backpressure turbo-generators with all auxiliaries) may reach 80 per cent, a figure which can be equalled by no other thermal power plant.

As heating steam is required, a boiler plant must in any case be provided, so that all the normal costs of the steam generation are incurred including

capital charges, fuel and wages. By inserting a simple backpressure turbine between the boilers and the heating system, power can be generated at very little additional expense; so little in fact, that even quite small generating units can compete successfully with the most modern super power stations. Moreover the cost of power transmission is eliminated.

In order to facilitate an estimate of the power which can be generated from a given quantity of heating steam, the diagrams given in figs. 1 and 2 may be used. In fig. 1 will be seen lines of absolute steam pressures and lines of total temperatures of steam in the super heated region. On the right hand side of the diagram is shown a scale for output in theoretical horse power obtainable out of 1,000 lbs. of steam per hour; also a scale for output in theoretical kilowatts obtainable out of 1,000 lbs. of steam per

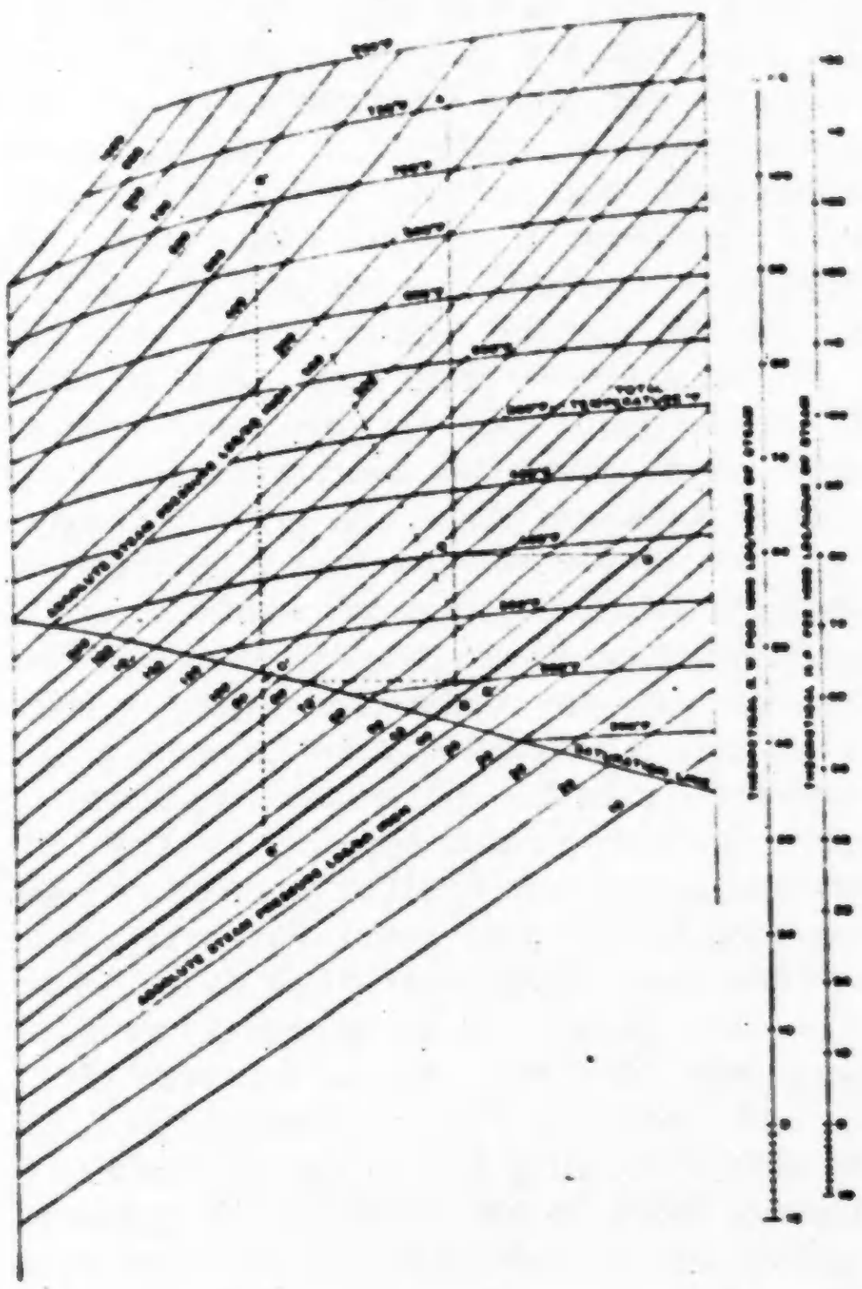

Fig. 1. Absolute steam pressure and temperature diagram.

hour. Theoretical output means the output obtainable on the assumption that the turbine or turbo set has no losses.

The absolute steam pressure and the steam temperature at the inlet of the turbine may be marked on the diagram, fig. 1. The point of intersection of the pressure and temperature line indicates the steam condition at the inlet of the turbine. If a vertical line from this point be drawn until the line indicating the absolute steam pressure at the outlet of the turbine is reached, the point of intersection of the vertical line and the line of absolute backpressure represents the steam condition at the outlet of the turbine, the latter being assumed as working without any losses. The distance measured on the scale between the two points, representing the inlet conditions on the one hand and the outlet conditions on the other hand, gives the output obtainable, either in theoretical horse power or theoretical kilowatts, when 1,000 lbs. of steam per hour is used in the turbine.

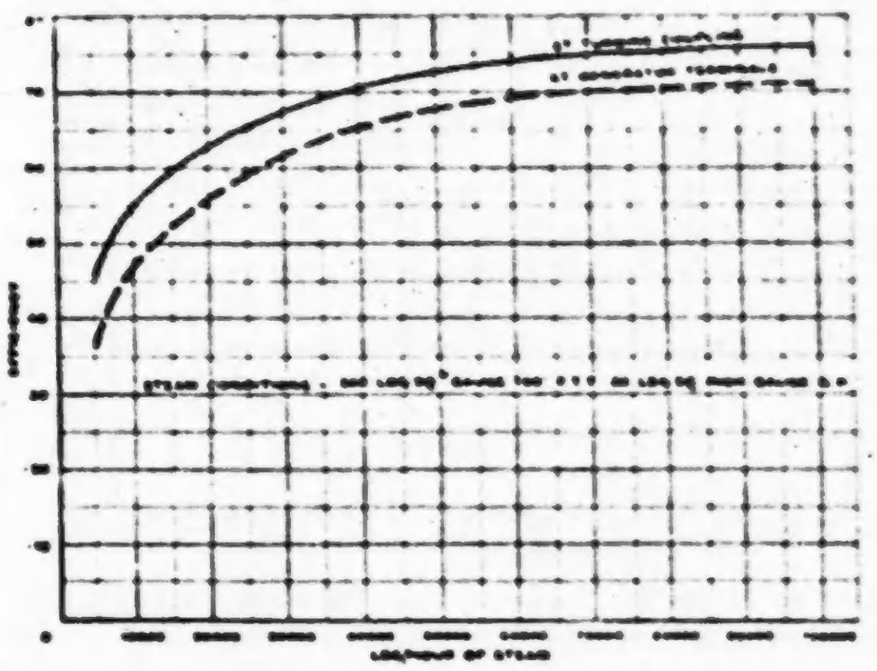

Fig. 2. Curve showing relationship between efficiency of turbine and steam quantity used per hour.

The diagram fig. 2 shows approximately the efficiency of the turbine or turbo set in relation to the steam quantity used per hour; this efficiency represents present-day average practice for a steam pressure of 350 lbs. per sq. in. with a steam temperature of 750° Fah. (both taken at the inlet of the turbine) and a back pressure of 30 lbs. per sq. in. It will suffice, however, for approximate estimates in conjunction with other steam conditions at the inlet and outlet of the turbine.

Having determined the quantity of steam per hour to be used in the turbine, the corresponding efficiency may be taken from the diagram given in fig. 2.

From the diagram, fig. 1, the theoretical output per 1,000 lbs. of steam per hour has been found, while fig. 2 has given the efficiency. By multiplying the theoretical output by this efficiency, the actual output per 1,000 lbs. of steam per hour is obtained. By multiplying this actual output by the ratio of the actual steam quantity in lbs. per hour to 1,000, the total actual output given by the total steam quantity used per hour is determined.

As an example, assume the steam pressure to be 350 lbs. per sq. in. and the steam temperature 750° Fah. at the inlet of the turbine; also that the steam pressure is 30 lbs. per sq. in. at the outlet of the turbine, the barometric pressure 30in. of mercury (or 14.7 lbs. per sq. in.), and the steam quantity

available for power generation in the turbine 75,000 lbs. per hour. The absolute steam pressure at the inlet of the turbine is 364.7 lbs. per sq. in.; the absolute pressure at the outlet of the turbine is 44.7 lbs. per sq. in. The line of absolute steam pressure of 364.7 lbs. per sq. in. intersects the line of 750° Fah. steam temperature at point A (diagram, fig. 1). The vertical line from point A intersects the line

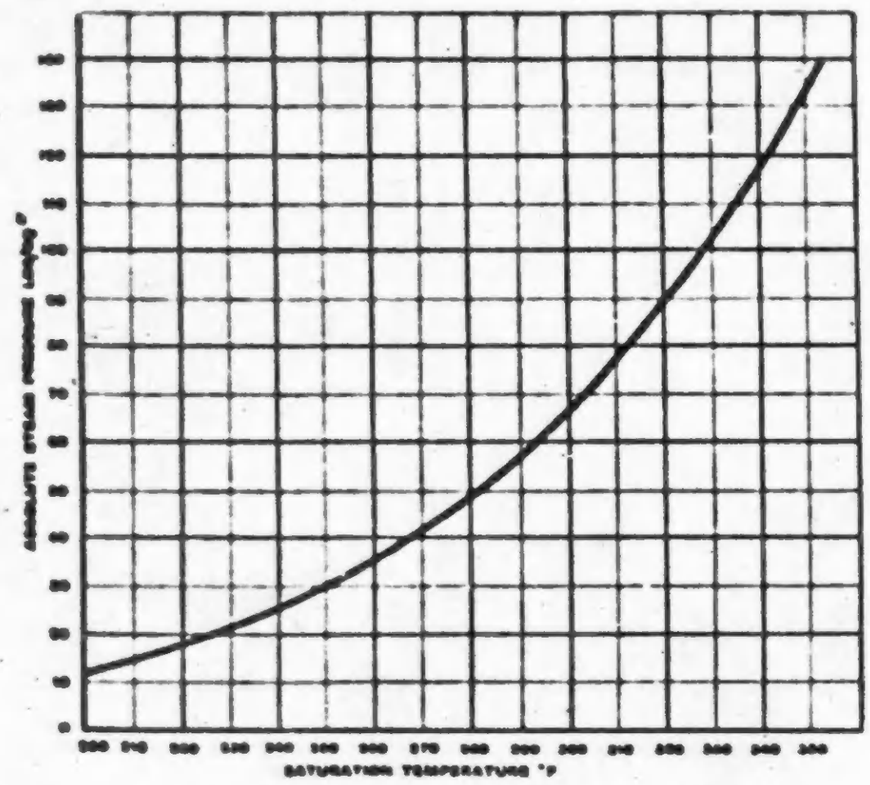

Fig. 3.—Relationship between absolute steam pressure and saturation temperature.

of absolute backpressure at point B; the distance A B measured on the two scales of the diagram represents 84 theoretical horse power or 63 theoretical kilowatts per 1,000 lbs. of steam used per hour. From the diagram, fig. 2, the efficiency corresponding to a steam quantity of 75,000 lbs. may be taken. The efficiency at the turbine coupling is .755, or the efficiency of the turbo set at the generator terminals is .702. The output measured at the turbine coupling with the conditions stated will therefore be:

$$84 \times \frac{75{,}000}{1{,}000} \times .755 = 4{,}756 \text{ b.h.p.}$$

or the output measured at the generator terminals:

$$63 \times \frac{75{,}000}{1{,}000} \times .702 = 3{,}317 \text{ kW.}$$

The backpressure is determined primarily by the steam temperature required for the process and is the pressure corresponding to this temperature assumed naturally as saturation temperature.

For instance, if a steam temperature of 250° Fah. is required for the process, then the steam pressure is 30 lbs. per sq. in. absolute. In the diagram, fig. 3, the relation between the absolute steam pressure and saturation temperature of steam is shown. Having established the steam pressure required for the process, the pressure loss in the steam main between the turbine and the heating apparatus is to be added to this pressure in order to determine the actual backpressure in the exhaust of the turbine. As the heat losses in the main are smaller with superheated steam than with saturated steam, it is desirable that the steam at the turbine exhaust should be slightly superheated. As saturated steam is preferred for the actual process, however, it follows that the superheat at the turbine exhaust should be such as practically to disappear at the heating apparatus.

Returning to the example, the distance A B in fig. 1, indicates the theoretical power. From fig. 2 it has been found that the turbine efficiency (at the turbine coupling) was .755, a figure which includes all losses in the turbine; the bulk of these losses affect the condition of the steam at the exhaust, and only a small part represents certain external losses (bearing friction, power for driving the oil pump and governor and leakage loss) which do not affect the steam condition at the turbine exhaust. As these external losses are comparatively small, it will be sufficient to use the efficiency (at the turbine coupling) in fig. 2 to determine the condition of steam in the turbine exhaust in the following manner (refer to fig. 1): make A B × .755 = A C; draw a horizontal line through C until it intersects the line of backpressure at point D. The point D represents the condition of steam in the turbine exhaust when the inlet steam pressure is 350 lbs. per sq. in., inlet steam temperature 750° Fah., backpressure 30 lbs. per sq. in., and the steam quantity to be used 75,000 lbs. per hour as given in the example. It will be seen that the total temperature of steam in the exhaust is 387° Fah. The saturation temperature corresponding to the backpressure of 30 lbs. per sq. in. is 274° Fah., hence the superheat is 113° Fah.

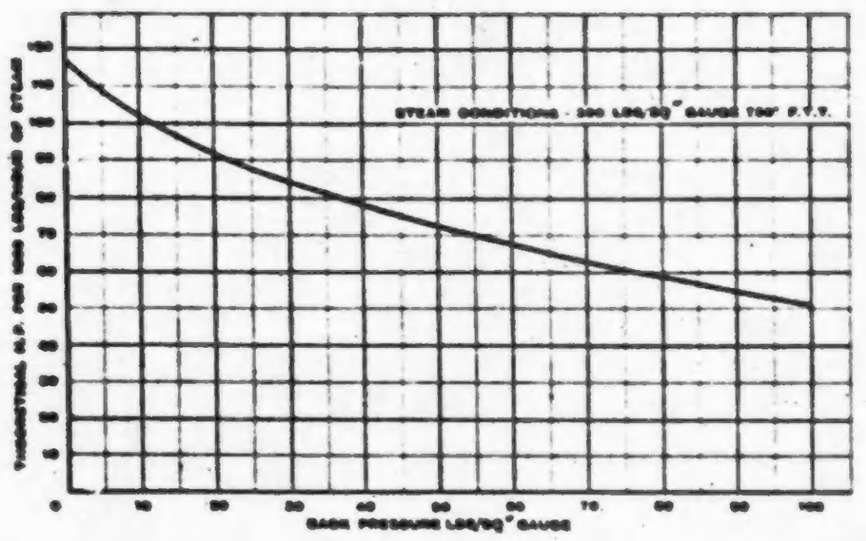

Fig. 4.—Influence of back pressure on theoretical horse power.

Such superheat, in most cases, would prove excessive for the process work, and to reduce it, one of the following two principal methods may be used.

A. A de-superheater may be applied (the excess superheat being used up for evaporation of injected water).

B. The steam conditions at the turbine inlet may be chosen (in the case of new or re-conditioned boilers) so as to obtain the desired superheat at

the turbine exhaust. Supposing this to be 27.5° Fah., point D' in fig. 1 represents this condition.

A horizontal line is now drawn through D' to the left, while anywhere on the left of D' a vertical line is drawn with points of intersection, C' and B'.

If $A'C'$ is made $= C'B' \times \frac{\text{turbine efficiency.}}{1 - \text{turbine efficiency}}$ any steam condition on the line $A'D'$ will fulfil the specified condition of superheat at the turbine exhaust.

It should be realised that the steam temperature in the exhaust depends on the load the turbine carries, hence it is necessary to base the determination of initial steam conditions on the average load.

The efficiency in fig. 2 represents present day average practice. It is naturally possible to construct a turbine for lower efficiency at a lower cost, and it is also possible to produce a turbine with higher efficiency at an increased cost. The actual power obtainable out of a given quantity of steam with a given steam pressure and temperature at the inlet, and a given backpressure is proportional to the turbine efficiency. It is obvious that this output is also affected by the steam pressure and the steam temperature at the turbine inlet and by the backpressure. This can easily be verified by means of the diagram in fig. 1. It will be seen that by increasing the temperature while the inlet pressure and the backpressure remain constant, the available output is increased. As increase of inlet temperature results in increased exhaust temperature, which may not be suitable unless de-superheaters are installed, it is not proposed to investigate further the influence on output of the variation of temperature. In some instances, however, it might be found desirable to increase the inlet steam temperature so as to obtain a greater output which would meet the demand, and then to use a de-superheater in the exhaust main.

A reference to the effect of inlet pressure and backpressure should therefore be useful. The diagrams figs. 4 and 5 illustrate these effects assuming the following set of steam conditions: steam pressure at turbine inlet, 350 lbs. per sq. in.; steam temperature at inlet 750° Fah.; exhaust pressure 30 lbs. per sq. in. With these conditions it will be seen from fig. 4 that the available theoretical output obtainable from 1,000 lbs. of steam per hour is 84 horse power.

Reducing the backpressure from 30 lbs. per sq. in. to 20 lbs. per sq. in., the theoretical output is increased to 92 horse power. On the other hand, by increasing the backpressure from 30 lbs. per sq. in. to 40 lbs. per sq. in., the available theoretical output is reduced to 77.8 horse power. From this it will be seen that the backpressure has a very profound influence on the available power. The backpressure can be reduced by reducing the losses in the steam main between the turbine and the heating apparatus, and this can be achieved by a layout involving a shorter steam main of ample cross section and with fewer bends.

The diagram in fig. 5 shows the variation of the available power with varying steam pressure at the turbine inlet (the inlet steam temperature remaining 750° Fah. and the backpressure 30 lbs. per sq. in.). By increasing the steam pressure from 350 lbs. per

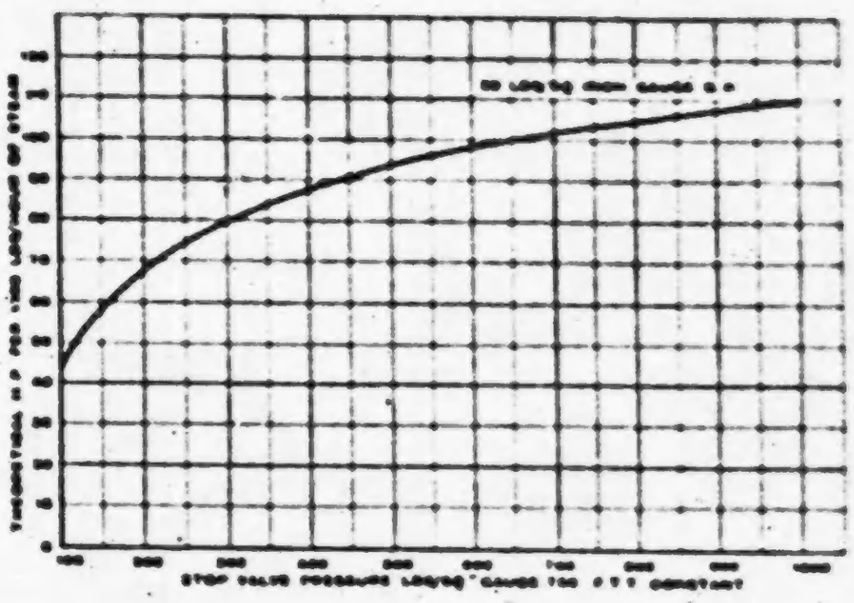

Fig. 5.—Influence of inlet pressure on theoretical horse power.

sq. in. to 470 lbs. per sq. in., the available output per 1,000 lbs. of steam per hour is increased from 84 h.p. to 92 h.p. Reducing the steam pressure from 350 lbs. per sq. in. to 278 lbs. per sq. in., this available theoretical output is reduced to 77.8 h.p. It will be seen from fig. 5 that the increase of available output due to increase in pressure is much more pronounced in the region of low steam pressures than in the region of high steam pressures. The increased inlet steam pressure involves increased cost of turbine, steam pipes and boiler plant. As a rule, the increased output due to reduced backpressure and increased inlet pressure is obtained at an increased capital cost, and *vice versa*. The increased steam pressure also involves a higher fuel consumption provided that the steam conditions at the turbine exhaust do not vary. Assuming that the turbine efficiency can be made the same for varying inlet steam conditions, then every additional b.h.p. of the turbine output requires an additional heat supply in steam at the turbine inlet at the rate of 2,550 B.T.U's per hour. The additional heat to be supplied by fuel to the boiler will then be $\frac{2,550}{f_n}$ B.T.U's per hour, f_n being the boiler efficiency.

If the boiler efficiency is taken as 83 per cent, every additional b.h.p. of output at the turbine shaft requires only 3,070 B.T.U's to be consumed as compared with about 10,000 B.T.U's in a modern super-power station. It may be remarked that an

Vapours	Mercury	Blue to white according to pressure.
		Green in special glass.
	Sodium—Yellow.	
	Cadmium—Greenish Blue.	
	Thallium—Green.	
	Magnesium—Grass green.	

A white light can be obtained from a neon tube in which a little mercury vapour is present—provided that just the correct quantity is maintained.

It will naturally be asked why cannot any desired hue of light be obtained by mixing in one tube any of these gases and vapours in the right proportions? Unfortunately the matter is not so simple as this. As already stated, each gas requires a unique value of voltage to stimulate it. If several gases or vapours are present in a tube together, in general, that requiring the lowest voltage to stimulate it will mask those which require high voltages to stimulate them—unless indeed their voltages have closely the same value. Thus the characteristic colour of the gas requiring the lowest voltage to stimulate it will dominate the hue of the radiation.

For instance it would seem to be a very attractive idea to use a mixture of sodium, mercury and neon in the same tube and combine their yellow, green, blue and red spectrum lines to obtain a good radiation. But for the reason given these will not work together in harness as we want them to. The willing horse does all the work.

This applies specially to the positive column. Near the cathode it frequently happens that when more than one gas is present, the characteristic colour of that requiring the higher ionisation voltage will show up, although it is masked in other parts of the tube. If we think for a moment we can see the reason for this. The gas with the higher excitation voltage can be excited near the cathode because the cathode fall of voltage takes place over a very short distance, and the speeds of the electrons here are higher. Thus for mixtures, a gas can be excited in the cathode fall region which in the positive column remains relatively inert.

In what has just been said we have assumed that plenty of each gas is present. If, however, we consider a tube containing a gas, together with such a metal as mercury which will evaporate as the tube gets hot, we find that at low temperatures the gas spectrum only will show, and at high temperatures only that of the mercury. But at some intermediate temperature both the gas and the vapour of mercury will be excited. The practical difficulty is to hold the temperature conditions in such a state of equilibrium that the radiation of both elements remains steady in the desired amounts.

POWER FACTOR.

Owing to the fact that the gas discharge does not obey Ohm's law, the wave form of the current or of the voltage across the tube is not a simple sine curve. Fig. 18 shows some typical oscillograms. In the case of a neon cold cathode tube it will be noticed that at the beginning of each cycle the voltage rises up to the value at which the discharge strikes and then it rapidly falls to a steady value, finally dropping sharply to zero at the end of the half cycle. Looking now at the oscillogram of the current, this of course remains zero until the voltage has risen to the striking value and then it rises, but only to fall to zero again just before the end of the half period. In the case of the mercury tube you will notice that the first peak is almost absent owing to the fact that the striking voltage is much nearer to the running voltage than in the case of neon. The oscillograms for hot cathode tubes are much the same, but the peak with neon is generally not so pronounced. The exact wave form depends on the type of tube and on the circuit conditions. How does this wave form affect the power factor?

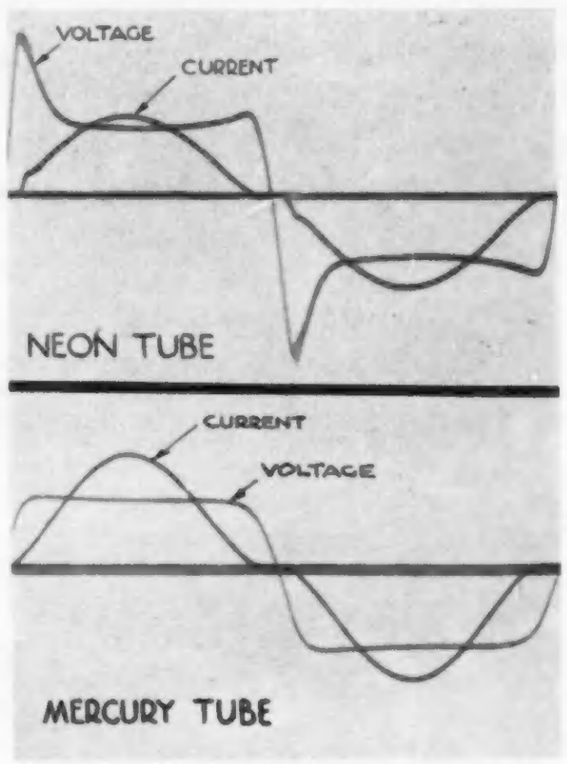

Fig. 18—Oscillograms of discharge tubes.

If a supply voltage is applied to a simple circuit consisting of an inductance and capacity, the product of the current and voltage multiplied by the power factor gives, as everyone knows, the true watts dissipated in the circuit. When the applied voltage is sinusoidal, the power factor is readily calculated in terms of the values of the inductance and capacity and it becomes unity when these values are zero, or bear a certain definite relation to one another. But if the sinusoidal potential is applied to a circuit not obeying Ohm's law then the power factor will not be unity, even if no inductance or capacity is in the circuit.

Engineers in the past became so accustomed to being able to assume that their wave forms were sinusoidal and their loads, for practical purposes, ordinary inductances or capacities that the power

factor became synonymous with Cos ϕ—the cosine of the angle by which the current lagged behind the voltage. They were apt to forget that the sinusoidal wave was only a very special case in the whole power factor problem. With discharge tubes, whilst we can and do use condensers to eliminate the current lag caused by the series choke and thereby cause the beginning and the end of each current half cycle to coincide with the beginning and end of its voltage half cycle, yet owing to the considerable wave form distortion produced by the discharge, the power factor will still be less than unity. Hence, as we add capacity to our circuit the power factor improves up to a point, but then as we add more it begins to drop back again without reaching unity. It turns out in practice that a power factor of at least 0.8 can readily be obtained in this way with cold cathode tubes running on leakage transformers. With hot cathode tubes the same applies and, in

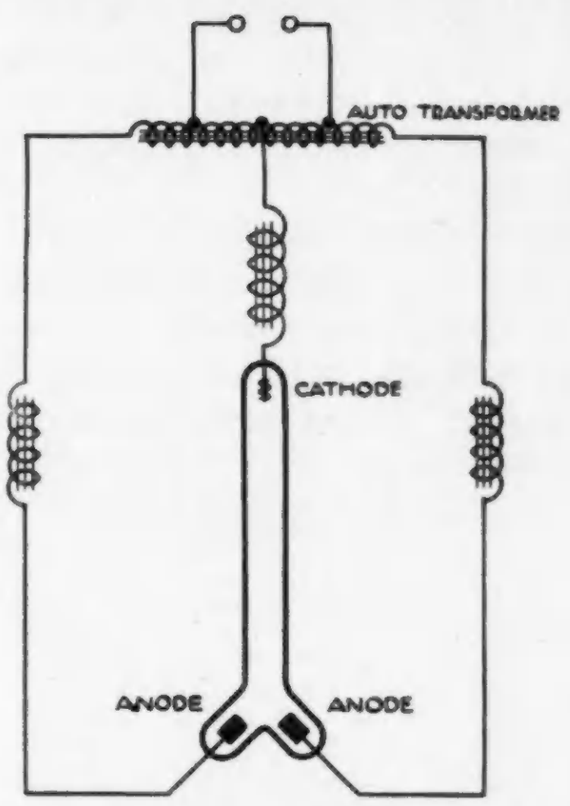

Fig. 19.—Circuit for double anode tube.

fact, even better correction (0.95 for example) can be achieved with some of the more important new types.

SUCCESSIVE IMAGE EFFECT.

We hardly notice the 50 cycle alternations of supply voltage when applied to an ordinary incandescent lamp because the filament does not seriously cool down between successive half cycles. On the other hand, gas discharge tubes follow the current changes more closely and therefore the "successive image" effect of moving objects is more marked, and is sometimes a nuisance when objects are moving rapidly.

If a three phase supply is available this effect can be practically eliminated by running nearby tubes on alternate phases. This, however, is not generally feasible so that we have to consider what other means is available.

Suppose we construct the tube with two anodes at one end and a cathode at the other and connect it up as shown in fig. 19. It is easily seen that current will flow through the tube in the same direction at each half cycle, but first through one half of the circuit and then through the other. The effect of the inductance in the circuit is to cause the current half cycles to overlap, and if its value is high enough it will practically eliminate the successive image effect. The only disadvantage of this system is that it needs so much gear for each tube.

The effect is one which must be reckoned with. My impression is that it is not so troublesome as the so called "flicker" effect on 25 cycle supplies with ordinary lamps—but only experience under all conditions will settle this.

PHOTOMETRY.

Complications of a serious kind arise when we try to think of the luminous output of coloured discharge tubes in terms of candle power—for the standards of candle power we use for comparison give white—not coloured—light.

Some very broad issues arise here. There are those who claim that even when we have achieved, on the basis of the laws of physics, an accurate comparison of our coloured discharge lamps with our candle power standards, the result is not a true gauge of the effectiveness of these light sources to aid human vision in discriminating objects. It is suggested that physiologically one colour is better than another for seeing with, and particularly that if the coloured light is monochromatic—that is, restricted to one narrow band of the spectrum, the optical system of the eye can focus objects more accurately, and so get effectively more out of a candle than if the light source emits over the whole spectrum. Whilst this is undoubtedly true in the discrimination of fine detail—there has yet been no proof that we should be justified in multiplying physical candle power by a coloured light factor to turn them into a higher or a lower value of—shall we say—"Physiological" or "Effective" candles.

This would be equivalent to saying for instance that 50 candle power of neon light is equal to 65 candle power of daylight, or of tungsten light, and that we must therefore multiply up all our values of neon lamp candle power by this factor and give the neon lamp this advantage.

If such claims for monochromatism are made they should be discounted—if for no other reason than that strictly monochromatic illumination causes all objects to appear of the same colour. They differ only in brightness. The alleged greater effectiveness of discharge tube illumination would only therefore be secured at the cost of complete distortion or elimination of the colour of objects. This would be too high a price to pay, except in a few special instances.

The basis of measurement of candle power of these coloured sources in terms of our ordinary units is not yet established. For good or for ill the past has bequeathed to us a unit of light intensity based on sources which produce a continuous spectrum. Hitherto our sources of light, whether the sun or incandescent solids emit light of all colours; the various sources differing, in that the proportions of light of the different colours are not equal.

Whilst it is true that these differences introduce certain difficulties when it is desired to compare the light-giving power of two such sources, to a high

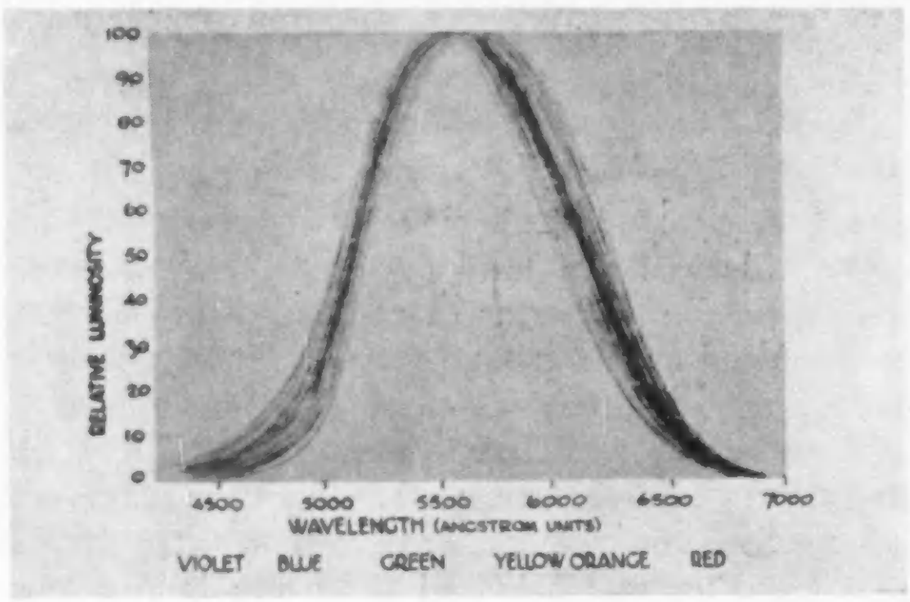

Fig. 20.—Relative luminosity curves (125 persons).

accuracy, yet no very serious difficulty is in general encountered by the individual observer.

Before passing on to consider the evaluation of the light-giving power of discharge lamps which only emit light of one or two colours, let us first examine a little in detail what is involved in making these measurements.

In fig. 20* is shown a mass of curves each one of which represents for one observer the brightness which a white surface would appear to have when a constant amount of radiant energy of different wavelengths falls upon the surface. Not only does the colour of the surface appear to change as the wavelength or frequency of the radiation changes, but also its brightness. The vertical ordinate of each of these curves at any point is proportional to the apparent brightness of the surface to one observer.

You will see how different these curves are liable to be for different observers by noting the spread on any vertical ordinate.

To compare the light emitting powers of two incandescent bodies (say carbon filament and tungsten filament or two tungsten filaments at different temperatures) which differ in the proportion of light of different colours emitted, three methods are often employed, which in general yield a different result for any particular observer and also different results for different observers.

The methods are:

(*a*) The direct contrast method where two parts of a surface in juxtaposition are viewed simultaneously and the distances of the sources from the surface adjusted till both parts appear equally bright.

(*b*) The flicker method where the two sources illuminate two parts of a surface which are viewed in rapid succession; the position of the sources is adjusted until the flickering effect produced is reduced to a minimum.

(*c*) The filter method (using spectrophotometer).

In this method a filter is chosen which, when placed in front of a standard source modifies the colour of the light in such a way that it appears to have the same colour as the other source whose candle power is unknown.

In order to find the candle power of the standard source modified by the filter, the following steps are necessary. The transmission of the filter for each wavelength is measured on a spectrophotometer, an instrument by which the contrast method of measurement is carried out without colour difference.

The next step is to determine for the standard source the relative amount of energy it radiates in each wavelength.

Lastly, the relative luminosity of the radiation averaged for a large number of observers for the different wavelengths is obtained. (This is determined from data illustrated by fig. 20).

This long series of observations is then utilised as follows:

Wave-length A.U.	Filter trans-mission.	Relative Energy.	Relative Lumin-osity. (Visibility)	Product of Cols. 2, 3 and 4.	Product of Cols. 3 and 4.
Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6
4000	.52	0.77	.004	.0016	.0031
4200	.54	1.18	.040	.0255	.0472
4400	.57	1.71	.230	.2242	.3933
—	—	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—
				Sum X	Sum Y
Filter Transmission = $\frac{X}{Y}$					

The sum of the products given in Columns 5 and 6 are then determined and the ratio of the sum of Column 5 to the sum of Column 6 gives the transmission factor of the filter for the composite light of the standard source, and for the hypothetical average eye. Then the candle power of the standard source combined with the filter is obtained from the known candle power of the standard source above, multiplied by the transmission factor of the filter just determined. Then this combination of standard source and filter can be used as a new standard of closely the same colour as the unknown source, to measure the candle power of the latter by the ordinary methods.

*Reproduced from Coblentz & Emerson, Bull. Bureau Stds. Vol. 14, p.206 (1918)

These three methods when used in photometric laboratories of the highest class, utilising the most refined methods, have not yielded agreement better than ± 2.0 per cent when comparing a carbon lamp with a tungsten lamp.

Now when attempting to measure a sodium or neon discharge lamp the difficulties outlined above become very much enhanced. However, in principle the same procedure has to be adopted.

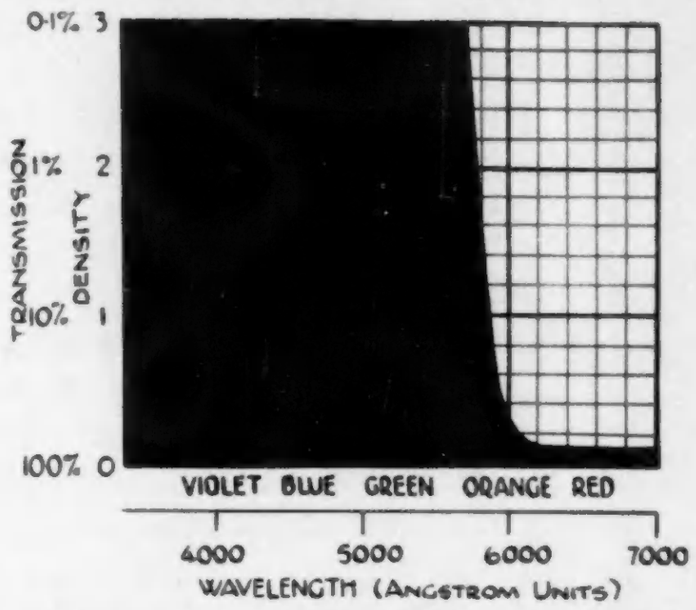

Fig. 21.—Transmission curve of filter used over tungsten lamp to produce approximate neon colour.

The properties of the filter chosen to modify the light from a tungsten lamp so that it closely matches the colour of a neon lamp are illustrated in fig. 21.

By determining the transmission factor of this filter for the light of the tungsten filament lamp by all three of the above methods, and then utilising this when making direct comparisons between

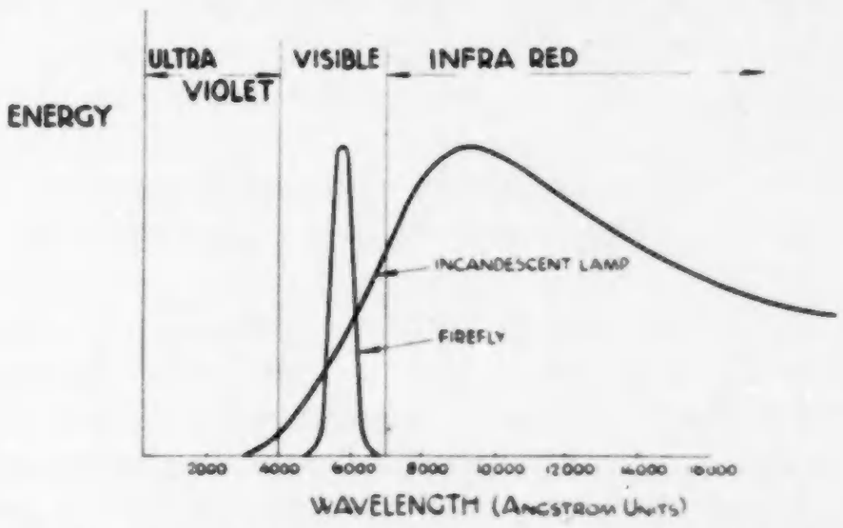

Fig. 22.—Energy distribution of firefly and incandescent lamp.

tungsten and neon lamps, a reasonable approximation to the candle power of the neon lamp can be made.

FACTORS AFFECTING EFFICIENCY.

A word now on the subject of the efficiency of discharge tubes. We must think of this as influenced first by external and then by internal factors. The external factors are the losses in the series reactance, which is introduced to counteract the negative resistance of the tube. Also there are very small losses in the condensers used to correct the power factor. These electrical losses are of course obvious to every electrical engineer. The internal factors which influence the efficiency are much more numerous and complex. Some gases and vapours are intrinsically more efficient as light sources than others, not only because they emit radiation at wavelengths lying in the parts of the visible spectrum to which the eye is most sensitive, but also because they emit comparatively little outside this range. A source which emits most of the energy in the visible region will naturally have a greater luminous efficiency than one which emits a considerable amount of infra red or ultra violet radiation. The fire fly, for example, emits a continuous spectrum but practically the whole of it lies between the green and the red limit of the spectrum. The maximum emission is

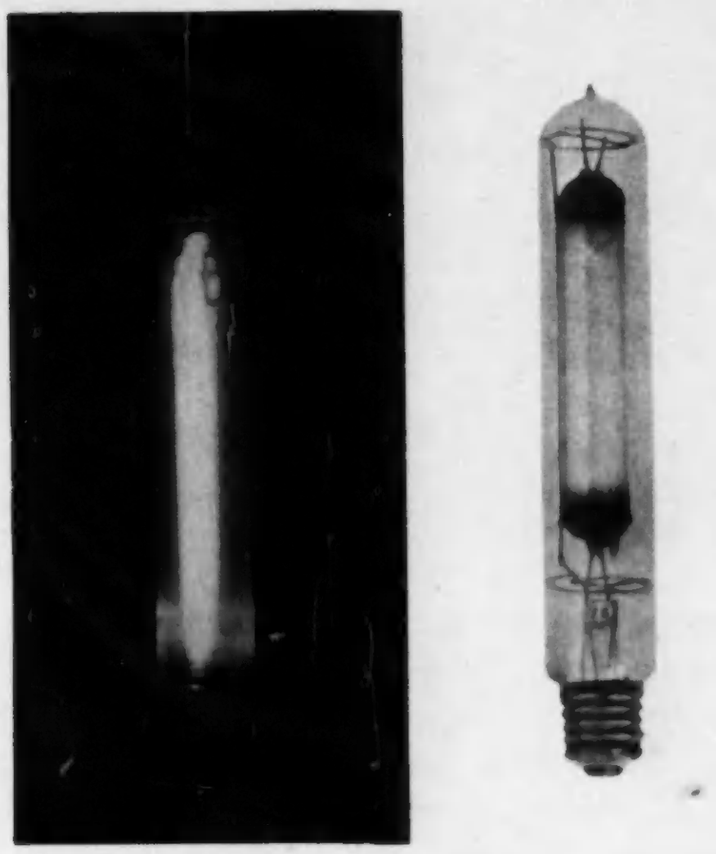

Fig. 23.—New G.E.C. "Wembley" lamp.

in the yellow green at 5,700A. If you compare the energy distribution for the fire fly and for an ordinary lamp, as shown in fig. 22, you will see the very large proportion of the energy which is emitted in the infra red by the lamp. The fire fly, on the other hand, restricts its radiation to the visible spectrum and in consequence is an extremely efficient light source.

It is, however, a very feeble one; about 1,600 fire flies all glowing at the same time would be required to give one candle power.

In the case of excited gases we have seen that, instead of continuous spectra, they emit radiation of certain wavelengths only. If all the energy supplied to a discharge tube were emitted at a wavelength of 5,550A., corresponding to the peak of the relative luminosity curve of the eye, the luminous efficiency would be in the neighbourhood of 670 lumens per watt, compared with that of a 100 watt incandescent lamp with an efficiency of only 12 lumens per watt. 92 per cent of the energy supplied to the incandescent lamp is radiated in the non-luminous portions of the spectrum. For reasons which we need not review

now, this considerable waste in the infra red is inevitable so long as the source of light is a hot body such, for example, as the filament of a lamp.

Let us now examine the radiation from one of these excited gases, taking a sodium lamp as the example. We find that, when it is burning under normal conditions, the energy emitted as infra red lines is only about one quarter of that emitted as the yellow D lines, as shown in fig. 8. The energy corresponding to the remaining lines in the visible and ultra violet regions only amounts to a few per cent. Now from the visibility curve we find that sodium yellow light of wavelength 5,890A. is about 78 per cent as luminous as the green light corresponding to the peak at 5,550A. Taking all these factors into consideration we might expect a very high luminous efficiency, somewhere about 360 lumens per watt. This has in fact been achieved at low intensities and under artificial conditions by Pirani, but it cannot be done practically. In practice it is, however, now possible to make 100 watt sodium lamps to have an efficiency of 70 lumens per watt, a great increase over the 12 lumens per watt of the corresponding incandescent lamp! But what is to account for the difference between the theoretical 360 and the practical 70 lumens per watt? The answer is that so far, we have neglected all the losses in the tube itself. To understand these we must return to our discussion of the atomic processes going on in our tube. You will remember that when an electron flying through the gas collides with an atom, one of two things may happen. If its velocity is below a certain amount, the collision is elastic, while if it is greater than the critical value the atom is excited and may subsequently emit radiation. Previously we have studied the second of these processes, but what of the first? The electrons in an actual discharge tube are moving very fast and the result of all the elastic collisions is to speed up the atoms of the gas. The average velocity of the atoms in a gas is, of course, a gauge of its temperature, so that the result of the elastic collisions is that the gas gets hot. The gas, in turn, heats up the walls of the tube and this finally radiates in the infra red region. There are many other more complicated processes going on at the same time but all end in the one way; valuable electrical energy is finally turned into heat at the glass walls and thus lost. One would therefore be inclined to say that what we want is a set of conditions under which no elastic collisions take place and none of these other wasteful processes occur. This is more or less desirable in the case of gases but with some vapours, sodium in particular, it is not so. At room temperatures, hardly any sodium would exist in the tube as vapour, so that in order to vaporise the required quantity, the tube must be kept hot. In order to obtain a highly efficient sodium tube it has to be lagged by surrounding it with an evacuated outer jacket to retain the heat; at the same time the elastic collisions and the other wasteful processes must be reduced. The most efficient tube will then be one in which the lagging is the greatest possible, and the heat producing processes are reduced to the minimum required to maintain the inner tube at the required temperature. If this be chosen too low, there will be insufficient sodium atoms present, while if it be too high the efficiency will drop because a greater proportion of the input energy is used up in the heat producing processes.

Fig. 24.—Discharge tube street lighting by new G.E.C. "Wembley" lamps.

This is a relatively simple case. With other vapours such, for example, as mercury, other factors, some of them extremely important, must be considered. But an attempt to deal with these here would lead us now into too great detail.

RECENT DEVELOPMENTS.

As you will recognise, the development of hot cathode tubes has proceeded very quickly during the last year or so, and many types are now rapidly approaching a commercial stage. Let us briefly review some of the lamps and units which have reached various stages of development. If some particulars have to be omitted it is because it is difficult to discuss technical developments which are incomplete and not as yet properly incorporated in commercial products.

First of all, by placing neon and mercury tubes (the latter in either clear or green glass) in parabolic reflectors, very effective units are obtained suitable

for the colour floodlighting of buildings, and the like. The efficiency of these is very greatly in excess of the ordinary incandescent lamps when combined with the colour filters which at present have to be used for this purpose. Then, by combining a neon and a mercury tube, the latter in a special fluorescent glass, a unit is obtained which emits a very pleasant light giving good colour rendering of objects. In this unit the tubes are enclosed behind opal glass sheets which mix and diffuse the light. Another development is the combination of hot cathode tubes with incandescent lamps. Neon tubes in this case tint the light and give it a rosy hue, blue mercury tubes give a daylight effect and also supply ultra violet light, if required. The advantage of this combination is that the incandescent lamps not only give useful light but owing to their being in series with the discharge tubes, they act in place of choke coils.

Secondly, we come to a very interesting new type of tube which has recently been developed at the G.E.C. Laboratories at Wembley. It is made at the moment in 400 watt units. This type, which is beginning to emerge from its experimental stage, consists of a vertical tube in which the discharge takes the form of an extremely brilliant narrow cord of light about 6 inches high. The efficiency of a 400 watt lamp of this type is at present about 40 lumens per watt (as compared with 15 lumens per watt for a corresponding tungsten lamp), but higher values than this have been obtained in experimental tubes. The light from this lamp is deficient in red but, if combined for instance with a neon tube, much better colour rendering would be obtained. It would seem that, when fully developed, this type of lamp should be particularly suitable for lighting streets and important thoroughfares. The street outside the Laboratories is at present illuminated entirely by these lamps in which, however, the colour is not yet corrected. The effect is striking though not yet as good as future developments can make it. This Wembley installation was first run at the beginning of July, 1932.

Thirdly there is the sodium lamp, which emits practically only a pure yellow light. This type of lamp was first developed by Pirani of the Osram Company, Berlin, whose researches showed how a glass could be made to withstand the attack of hot sodium vapour throughout hundreds of hours. A similar lamp of modified construction has also recently been developed by the Philips Company in Holland. There is an excellent section of road lighted with these in Holland and another in Zurich. The practical applications of the sodium tube have been specially studied by the Germans and the Dutch. The author showed early examples of sodium lamps two years ago at the Institution of Electrical Engineers—and further types have been under development. A type developed by Pirani, of which examples have recently been constructed at Wembley already yields 70 lumens per watt. The sodium lamp lends itself to small wattage sizes of 80 to 150 watts, but in view of the extreme colour distortion produced by the sodium lamp it is not very suitable at present for general lighting or even for lighting ordinary streets. It is however, being tried for lighting stretches of arterial and country roads where the lack of good colour discrimination is of little importance and where the illumination is nearer those lower levels at which the eye in any case is not accustomed to distinguish colour. In other words, if the illumination is so low that the cones of the retina are out of action and we are using only rod vision—it does not so much matter if the light is monochromatic.

Fig. 25.—Discharge tube lighting by Phillips, Holland.

As for the future, who would care to predict what possibilities lie in store for us, after we have seen the rapid progress which has taken place in this fascinating field during the last year? But of this one can feel sure—once these new tubes reach the commercial stage, the next developments must proceed along the lines of improving first the colour and then, still further, the efficiency. Furthermore, much effort will have to be spent on adapting the different types to the varied illumination requirements of street and building. Meanwhile we may be confident that further fundamental research will reveal the possibilities of other new types of lamp—for many avenues still lie open to be explored.

Steam Turbines for Combined Supply of Power and Heating Steam.

By B. POCHOBRADSKY, M.I.Mech.E.

Chief Engineer, Fraser & Chalmers Engineering Works of The General Electric Co., Ltd.

PUBLIC electric power supply tends to be concentrated in a small number of large power stations; from these the power is transmitted to more or less distant places whence it is distributed to a large number of consumers. The cost of power at the point of consumption therefore includes the cost of production, transmission and distribution. As the first two operations are performed on a large scale, the cost of power is, generally speaking, smaller than if power had been generated in a large number of small stations and transmitted over a shorter distance. The bulk of this power is generated in this country and other coal-producing countries by means of condensing steam turbines, as this type of prime mover has given the most satisfactory results.

It is interesting to note that the overall thermal efficiency of large power stations equipped with steam turbines has reached about 24 per cent. This means that about 24 per cent of the potential heat of coal is transformed into useful electrical energy, the remaining 76 per cent escaping as loss to atmosphere (heat in flue gases, radiation and leakages) and to cooling water (through condensers, oil coolers and air coolers).

The overall thermal efficiency can be improved by increasing the steam pressure and temperature, by the adoption of interstage re-heating and other means. The extent of the possible improvement however, is small, and it can be assumed that about 26 per cent overall thermal efficiency will be a representative figure for large power stations for a number of years to come.

In many industries steam is used for process work such as drying and boiling, while in others and in large institutions, considerable quantities of steam are used for ordinary heating purposes. In the first category may be mentioned:

Paper and cellulose manufacture.
Spinning, weaving and dyeing.
Artificial silk manufacture.
Breweries and distilleries.
Leather and rubber industries.
Oil refineries.
Sugar, cocoa and sugar goods industries.
Manufacture of chemicals, fertilizers, dyes and drugs.
Gramophone records.
Potteries.
Furniture industries.
Laundries.
Manufacture of explosives.
Soap industry.
Etc., etc.

To the second category (steam for ordinary heating purposes) belong many large industrial plants, stores, hotels, hospitals, banks and the like.

In these establishments, while steam is used for process or heating purposes, power is required at the same time for lighting, lifts and driving machinery of all kinds. In all these instances this combined power and heating steam supply can be provided by special steam turbines of the back-pressure, passout-backpressure or passout type, and it is the purpose of this article to show the economic advantages obtained by installing turbines of this type where power generation and heating steam supplies are required.

BACKPRESSURE TURBINES.

Of the three types of turbine mentioned, the simplest is the backpressure turbine. Steam is led from the boilers to a backpressure turbine, in which part of the steam energy is utilised for power generation and the remaining heat is used for process work or heating, a very small percentage being lost. All the internal losses in the turbine re-appear as heat in the heating steam, the only losses being the very small radiation, bearing friction, leakage loss and power for driving the lubricating oil pump and governor. As there is no lubrication in the steam spaces of a turbine, the steam leaving the turbine is not contaminated by oil, a feature which is a great advantage in regard both to heat transmission and to the process work itself.

Assuming that the total useful output of such a turbine is made up of the power generated and the total heat delivered to the heating system, the overall thermal efficiency of the whole steam plant (consisting of boilers and backpressure turbo-generators with all auxiliaries) may reach 80 per cent, a figure which can be equalled by no other thermal power plant.

As heating steam is required, a boiler plant must in any case be provided, so that all the normal costs of the steam generation are incurred including

capital charges, fuel and wages. By inserting a simple backpressure turbine between the boilers and the heating system, power can be generated at very little additional expense; so little in fact, that even quite small generating units can compete successfully with the most modern super power stations. Moreover the cost of power transmission is eliminated.

In order to facilitate an estimate of the power which can be generated from a given quantity of heating steam, the diagrams given in figs. 1 and 2 may be used. In fig. 1 will be seen lines of absolute steam pressures and lines of total temperatures of steam in the super heated region. On the right hand side of the diagram is shown a scale for output in theoretical horse power obtainable out of 1,000 lbs. of steam per hour; also a scale for output in theoretical kilowatts obtainable out of 1,000 lbs. of steam per

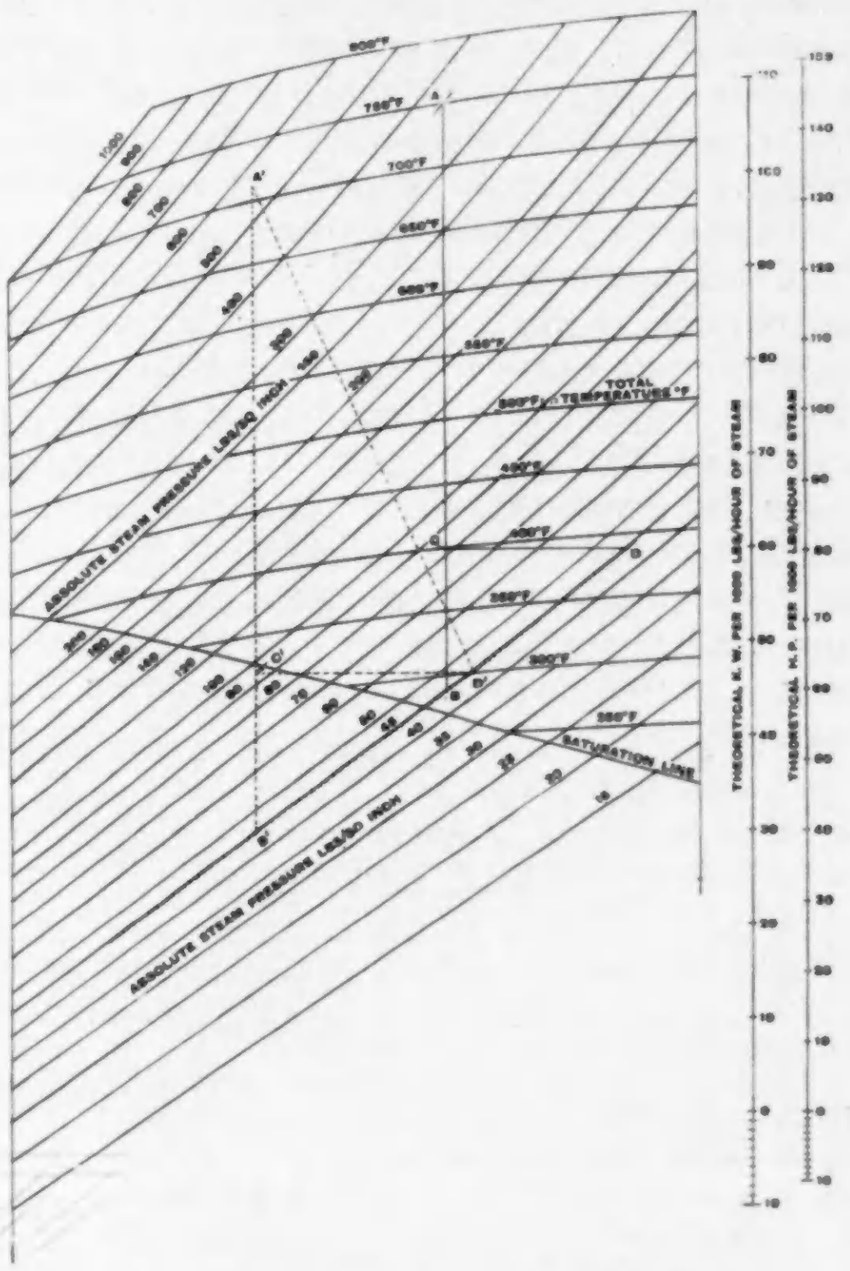
TOTAL TEMPERATURES °F
ABSOLUTE STEAM PRESSURE LBS/SQ INCH
SATURATION LINE
THEORETICAL K. W. PER 1000 LBS/HOUR OF STEAM
THEORETICAL H.P. PER 1000 LBS/HOUR OF STEAM

Fig. 1.—Absolute steam pressure and temperature diagram.

hour. Theoretical output means the output obtainable on the assumption that the turbine or turbo set has no losses.

The absolute steam pressure and the steam temperature at the inlet of the turbine may be marked on the diagram, fig. 1. The point of intersection of the pressure and temperature line indicates the steam condition at the inlet of the turbine. If a vertical line from this point be drawn until the line indicating the absolute steam pressure at the outlet of the turbine is reached, the point of intersection of the vertical line and the line of absolute backpressure represents the steam condition at the outlet of the turbine, the latter being assumed as working without any losses. The distance measured on the scale between the two points, representing the inlet conditions on the one hand and the outlet conditions on the other hand, gives the output obtainable, either in theoretical horse power or theoretical kilowatts, when 1,000 lbs. of steam per hour is used in the turbine.

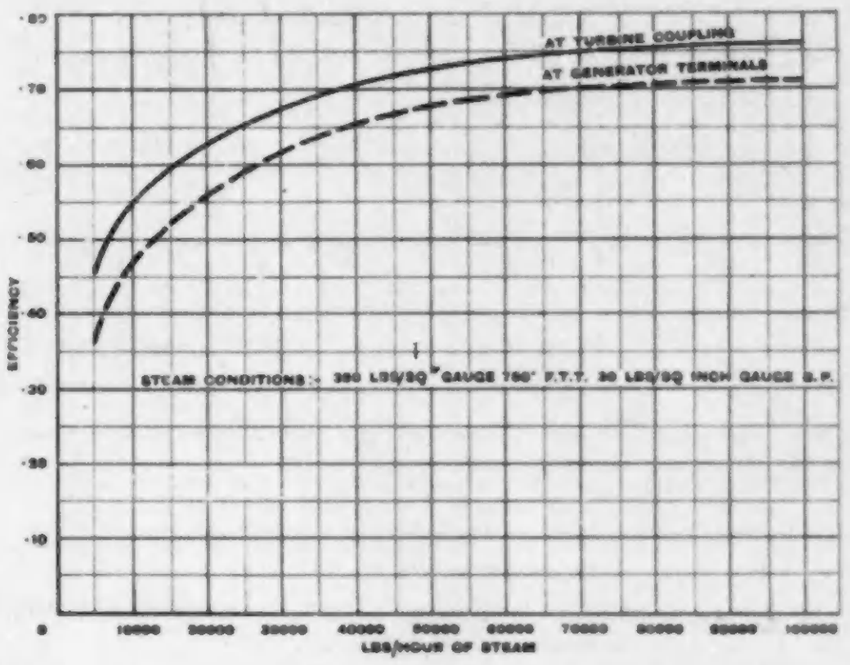
AT TURBINE COUPLING
AT GENERATOR TERMINALS
EFFICIENCY
STEAM CONDITIONS :- 350 LBS/SQ" GAUGE 750° F.T.T. 30 LBS/SQ INCH GAUGE B.P.
LBS/HOUR OF STEAM

Fig. 2.—Curve showing relationship between efficiency of turbine and steam quantity used per hour.

The diagram fig. 2 shows approximately the efficiency of the turbine or turbo set in relation to the steam quantity used per hour; this efficiency represents present-day average practice for a steam pressure of 350 lbs. per sq. in. with a steam temperature of 750° Fah. (both taken at the inlet of the turbine) and a back pressure of 30 lbs. per sq. in. It will suffice, however, for approximate estimates in conjunction with other steam conditions at the inlet and outlet of the turbine.

Having determined the quantity of steam per hour to be used in the turbine, the corresponding efficiency may be taken from the diagram given in fig. 2.

From the diagram, fig. 1, the theoretical output per 1,000 lbs. of steam per hour has been found, while fig. 2 has given the efficiency. By multiplying the theoretical output by this efficiency, the actual output per 1,000 lbs. of steam per hour is obtained. By multiplying this actual output by the ratio of the actual steam quantity in lbs. per hour to 1,000, the total actual output given by the total steam quantity used per hour is determined.

As an example, assume the steam pressure to be 350 lbs. per sq. in. and the steam temperature 750° Fah. at the inlet of the turbine; also that the steam pressure is 30 lbs. per sq. in. at the outlet of the turbine, the barometric pressure 30in. of mercury (or 14.7 lbs. per sq. in.), and the steam quantity

available for power generation in the turbine 75,000 lbs. per hour. The absolute steam pressure at the inlet of the turbine is 364.7 lbs. per sq. in.; the absolute pressure at the outlet of the turbine is 44.7 lbs. per sq. in. The line of absolute steam pressure of 364.7 lbs. per sq. in. intersects the line of 750° Fah. steam temperature at point A (diagram, fig. 1). The vertical line from point A intersects the line

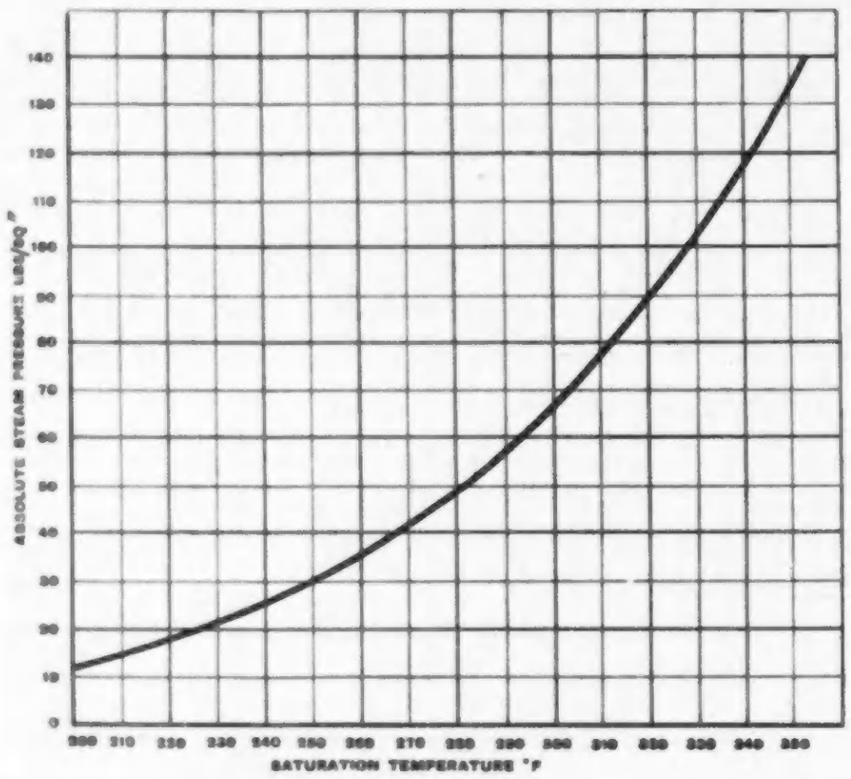

Fig. 3.—Relationship between absolute steam pressure and saturation temperature.

of absolute backpressure at point B; the distance A B measured on the two scales of the diagram represents 84 theoretical horse power or 63 theoretical kilowatts per 1,000 lbs. of steam used per hour. From the diagram, fig. 2, the efficiency corresponding to a steam quantity of 75,000 lbs. may be taken. The efficiency at the turbine coupling is .755, or the efficiency of the turbo set at the generator terminals is .702. The output measured at the turbine coupling with the conditions stated will therefore be:

$$84 \times \frac{75{,}000}{1{,}000} \times .755 = 4{,}756 \text{ b.h.p.}$$

or the output measured at the generator terminals:

$$63 \times \frac{75{,}000}{1{,}000} \times .702 = 3{,}317 \text{ kW.}$$

The backpressure is determined primarily by the steam temperature required for the process and is the pressure corresponding to this temperature assumed naturally as saturation temperature.

For instance, if a steam temperature of 250° Fah. is required for the process, then the steam pressure is 30 lbs. per sq. in. absolute. In the diagram, fig. 3, the relation between the absolute steam pressure and saturation temperature of steam is shown. Having established the steam pressure required for the process, the pressure loss in the steam main between the turbine and the heating apparatus is to be added to this pressure in order to determine the actual backpressure in the exhaust of the turbine. As the heat losses in the main are smaller with superheated steam than with saturated steam, it is desirable that the steam at the turbine exhaust should be slightly superheated. As saturated steam is preferred for the actual process, however, it follows that the superheat at the turbine exhaust should be such as practically to disappear at the heating apparatus.

Returning to the example, the distance A B in fig. 1, indicates the theoretical power. From fig. 2 it has been found that the turbine efficiency (at the turbine coupling) was .755, a figure which includes all losses in the turbine; the bulk of these losses affect the condition of the steam at the exhaust, and only a small part represents certain external losses (bearing friction, power for driving the oil pump and governor and leakage loss) which do not affect the steam condition at the turbine exhaust. As these external losses are comparatively small, it will be sufficient to use the efficiency (at the turbine coupling) in fig. 2 to determine the condition of steam in the turbine exhaust in the following manner (refer to fig. 1): make A B × .755 = A C; draw a horizontal line through C until it intersects the line of backpressure at point D. The point D represents the condition of steam in the turbine exhaust when the inlet steam pressure is 350 lbs. per sq. in., inlet steam temperature 750° Fah., backpressure 30 lbs. per sq. in., and the steam quantity to be used 75,000 lbs. per hour as given in the example. It will be seen that the total temperature of steam in the exhaust is 387° Fah. The saturation temperature corresponding to the backpressure of 30 lbs. per sq. in. is 274° Fah., hence the superheat is 113° Fah.

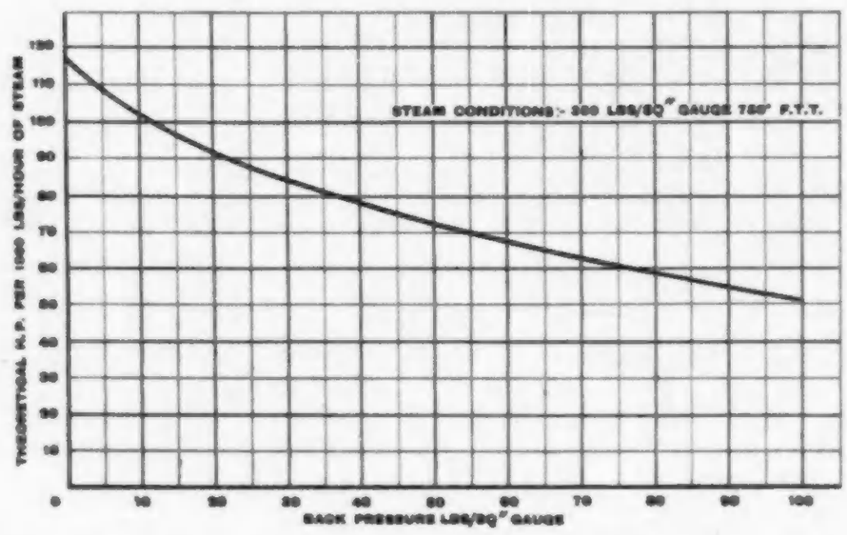

Fig. 4.—Influence of back pressure on theoretical horse power.

Such superheat, in most cases, would prove excessive for the process work, and to reduce it, one of the following two principal methods may be used.

A. A de-superheater may be applied (the excess superheat being used up for evaporation of injected water).

B. The steam conditions at the turbine inlet may be chosen (in the case of new or re-conditioned boilers) so as to obtain the desired superheat at

the turbine exhaust. Supposing this to be 27.5° Fah., point D' in fig. 1 represents this condition.

A horizontal line is now drawn through D' to the left, while anywhere on the left of D' a vertical line is drawn with points of intersection, C' and B'. If $A'\ C'$ is made $= C'\ B' \times \frac{\text{turbine efficiency.}}{1 - \text{turbine efficiency}}$ any steam condition on the line $A'\ D'$ will fulfil the specified condition of superheat at the turbine exhaust.

It should be realised that the steam temperature in the exhaust depends on the load the turbine carries, hence it is necessary to base the determination of initial steam conditions on the average load.

The efficiency in fig. 2 represents present day average practice. It is naturally possible to construct a turbine for lower efficiency at a lower cost, and it is also possible to produce a turbine with higher efficiency at an increased cost. The actual power obtainable out of a given quantity of steam with a given steam pressure and temperature at the inlet, and a given backpressure is proportional to the turbine efficiency. It is obvious that this output is also affected by the steam pressure and the steam temperature at the turbine inlet and by the backpressure. This can easily be verified by means of the diagram in fig. 1. It will be seen that by increasing the temperature while the inlet pressure and the backpressure remain constant, the available output is increased. As increase of inlet temperature results in increased exhaust temperature, which may not be suitable unless de-superheaters are installed, it is not proposed to investigate further the influence on output of the variation of temperature. In some instances, however, it might be found desirable to increase the inlet steam temperature so as to obtain a greater output which would meet the demand, and then to use a de-superheater in the exhaust main.

A reference to the effect of inlet pressure and backpressure should therefore be useful. The diagrams figs. 4 and 5 illustrate these effects assuming the following set of steam conditions: steam pressure at turbine inlet, 350 lbs. per sq. in.; steam temperature at inlet 750° Fah.; exhaust pressure 30 lbs. per sq. in. With these conditions it will be seen from fig. 4 that the available theoretical output obtainable from 1,000 lbs. of steam per hour is 84 horse power.

Reducing the backpressure from 30 lbs. per sq. in. to 20 lbs. per sq. in., the theoretical output is increased to 92 horse power. On the other hand, by increasing the backpressure from 30 lbs. per sq. in. to 40 lbs. per sq. in., the available theoretical output is reduced to 77.8 horse power. From this it will be seen that the backpressure has a very profound influence on the available power. The backpressure can be reduced by reducing the losses in the steam main between the turbine and the heating apparatus, and this can be achieved by a layout involving a shorter steam main of ample cross section and with fewer bends.

The diagram in fig. 5 shows the variation of the available power with varying steam pressure at the turbine inlet (the inlet steam temperature remaining 750° Fah. and the backpressure 30 lbs. per sq. in.). By increasing the steam pressure from 350 lbs. per

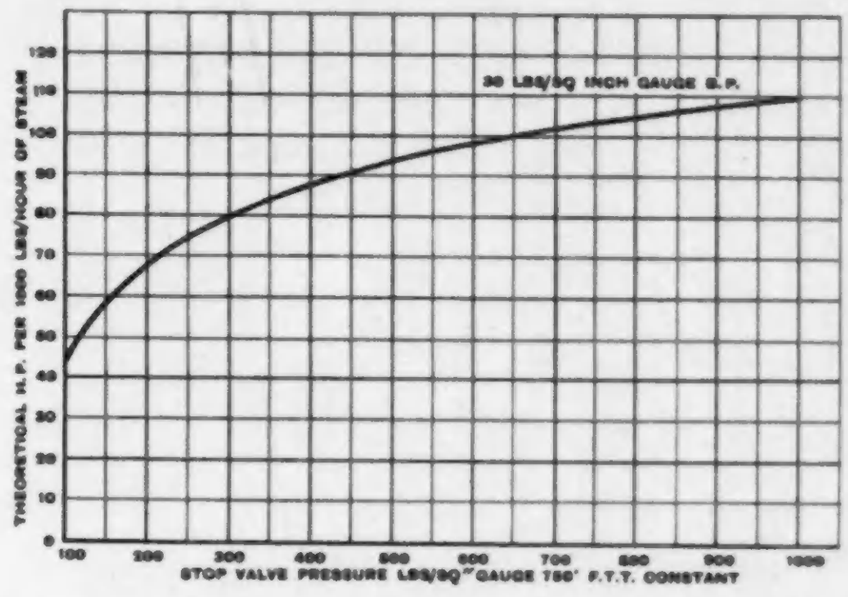

Fig. 5.—Influence of inlet pressure on theoretical horse power.

sq. in. to 470 lbs. per sq. in., the available output per 1,000 lbs. of steam per hour is increased from 84 h.p. to 92 h.p. Reducing the steam pressure from 350 lbs. per sq. in. to 278 lbs. per sq. in., this available theoretical output is reduced to 77.8 h.p. It will be seen from fig. 5 that the increase of available output due to increase in pressure is much more pronounced in the region of low steam pressures than in the region of high steam pressures. The increased inlet steam pressure involves increased cost of turbine, steam pipes and boiler plant. As a rule, the increased output due to reduced backpressure and increased inlet pressure is obtained at an increased capital cost, and *vice versa*. The increased steam pressure also involves a higher fuel consumption provided that the steam conditions in the turbine exhaust do not vary. Assuming that the turbine efficiency can be made the same for varying inlet steam conditions, then every additional b.h.p. of the turbine output requires an additional heat supply in steam at the turbine inlet at the rate of 2,550 B.T.U's per hour. The additional heat to be supplied by fuel to the boiler will then be $\frac{2,550,}{f_B}$ B.T.U's per hour, f_B being the boiler efficiency.

If the boiler efficiency is taken as 83 per cent, every additional b.h.p. of output at the turbine shaft requires only 3,070 B.T.U's to be consumed as compared with about 10,000 B.T.U's in a modern super-power station. It may be remarked that an

increase of output can be obtained by heating the boiler feed water with steam from the turbine. This would have the effect of increasing the heating steam quantity and as all steam passes through the turbine, greater output is produced. The overall thermal efficiency of the plant is not appreciably affected by this expedient.

The design of the turbine and its governing depends chiefly on (1) the steam quantity to be utilized; (2) the operating conditions and their fluctuations, and (3) the output demand. It is well known that the efficiency of a turbine stage depends on the ratio of the peripheral velocity to the steam velocity corresponding to the adiabatic heat drop in that stage. Whatever type of stage is chosen—a single impulse stage, a re-action stage, or a compound

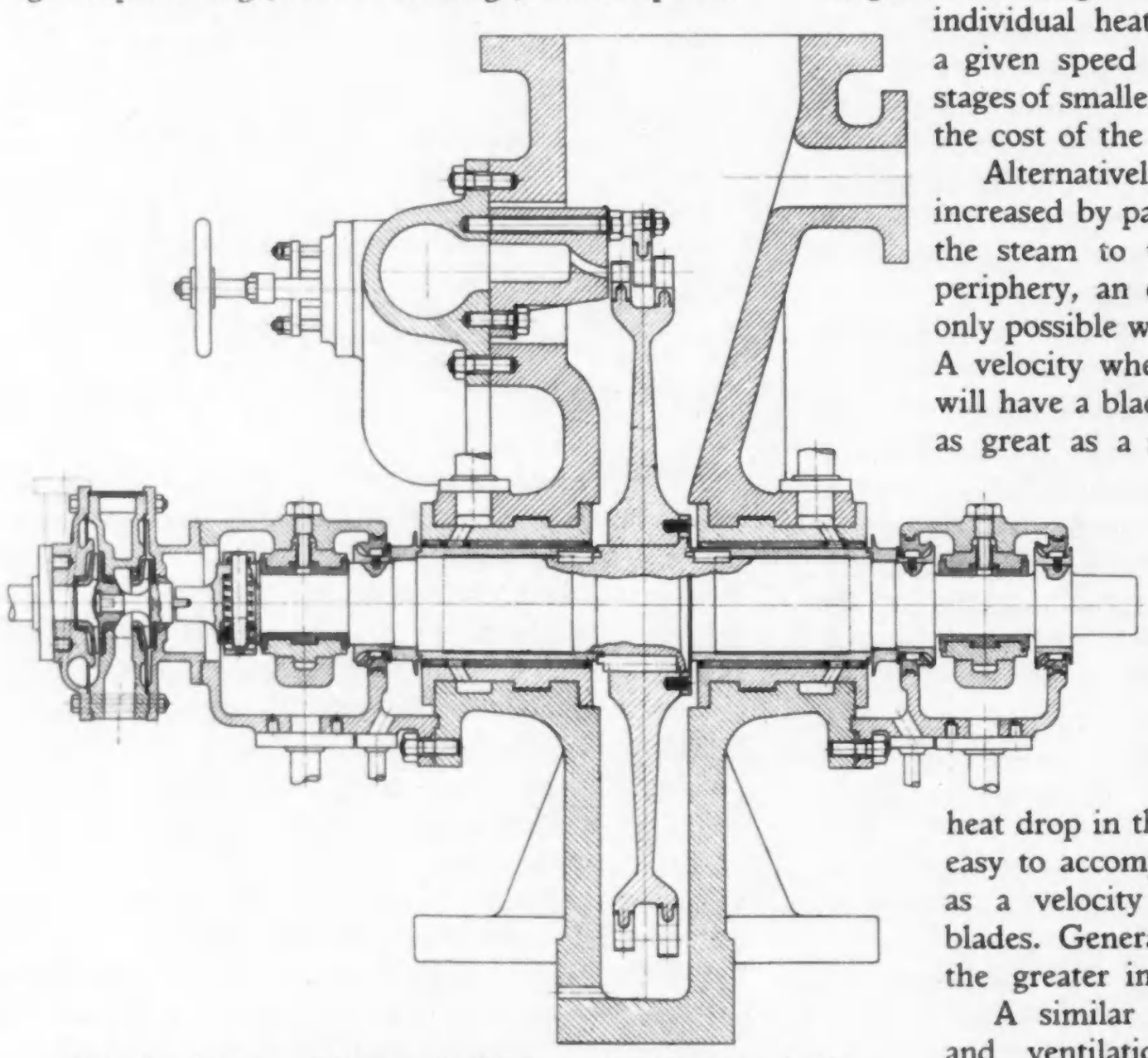

Fig. 6.—Section of Fraser & Chalmers single stage back-pressure turbine.

velocity stage with two or more rows of blades, each type has a maximum efficiency for a certain value of this ratio. Above that value, the cost of the turbine increases and the efficiency falls. Below the value, the cost of the turbine decreases and the efficiency also decreases, provided that other losses are not affected. In backpressure turbines, however, other influences are quite pronounced. Turbines of this type function in a higher region of steam pressure. Consequently, the volume of the steam is relatively less and therefore the blade height is comparatively small. Small blade height affects the efficiency adversely, the reduction being already appreciable just below 3in. blade height and extraordinarily rapid from a blade height of $\frac{5}{8}$in. downwards. Up to a certain limit it is possible to design a turbine having a reasonably efficient blade height. A turbine stage operating with a given heat drop and a given peripheral velocity at a speed of 6,000 r.p.m. will have double the blade height, compared with a stage operating at 3,000 r.p.m., with the same peripheral velocity, steam quantity and conditions. For this reason the speed of modern turbines has been increased and in many cases high speed turbines are coupled to generators by means of speed reducing gear.

Another effective method of increasing the blade height is to design the turbine stages for smaller individual heat drops, a method which for a given speed involves a larger number of stages of smaller diameter, thereby increasing the cost of the turbine.

Alternatively, the blade height can be increased by partial admission, *i.e.*, arranging the steam to work only in a portion of the periphery, an expedient which, however, is only possible with the impulse type machine. A velocity wheel with two rows of blades will have a blade height in the first row twice as great as a single row wheel for the same pressure drop.

Other losses which may be mentioned are due to gland leakages, friction and ventilation. The gland leakages at the high pressure end will be smaller if the pressure on that gland is smaller; hence it is often preferable to use a larger heat drop in the first stage. This method is easy to accomplish if the first stage is built as a velocity stage with, say, two rows of blades. Generally, the smaller the machine the greater influence has the leakage loss.

A similar argument applies to friction and ventilation losses. These considerations lead to the general conclusion that, for small backpressure turbines, one wheel (mostly with two rows of blades) is frequently the best design from the point of cost as well as efficiency.

Fig. 6 shows a section of a Fraser & Chalmers single stage backpressure turbine. This particular type has been actually used for outputs from 100 kW up to 500 kW. For machines of medium size a velocity wheel with two rows of blades as the first stage and a number of single stages is usually recommended. A section of this type is shown in fig. 7, which illustrates a Fraser & Chalmers back-pressure turbine having a moderate number of

stages, which has actually been used for outputs from 500 kW up to 5,000 kW.

For large output machines, especially with steady conditions, a large number of single stages of small diameter may show the best commercial result. Some of the backpressure turbines built at Fraser & Chalmers Engineering Works have twenty stages.

It would not be prudent to accept the foregoing argument without some degree of qualification. The fluctuation of the steam quantity has a pronounced influence, as with reduced steam quantities the output of the turbine will be reduced not only because the steam quantity is smaller but also because the turbine efficiency decreases with the falling steam quantity. The decrease of turbine efficiency, with falling steam quantity, is greater in a multi-stage machine than in a machine having a moderate number of stages. In fact, below some partial load, the cheap single stage turbine may be more efficient than the more expensive multi-stage turbines. When large fluctuations take place in steam quantities it is essential to compare the performance of the different types of turbine over the whole range of fluctuations.

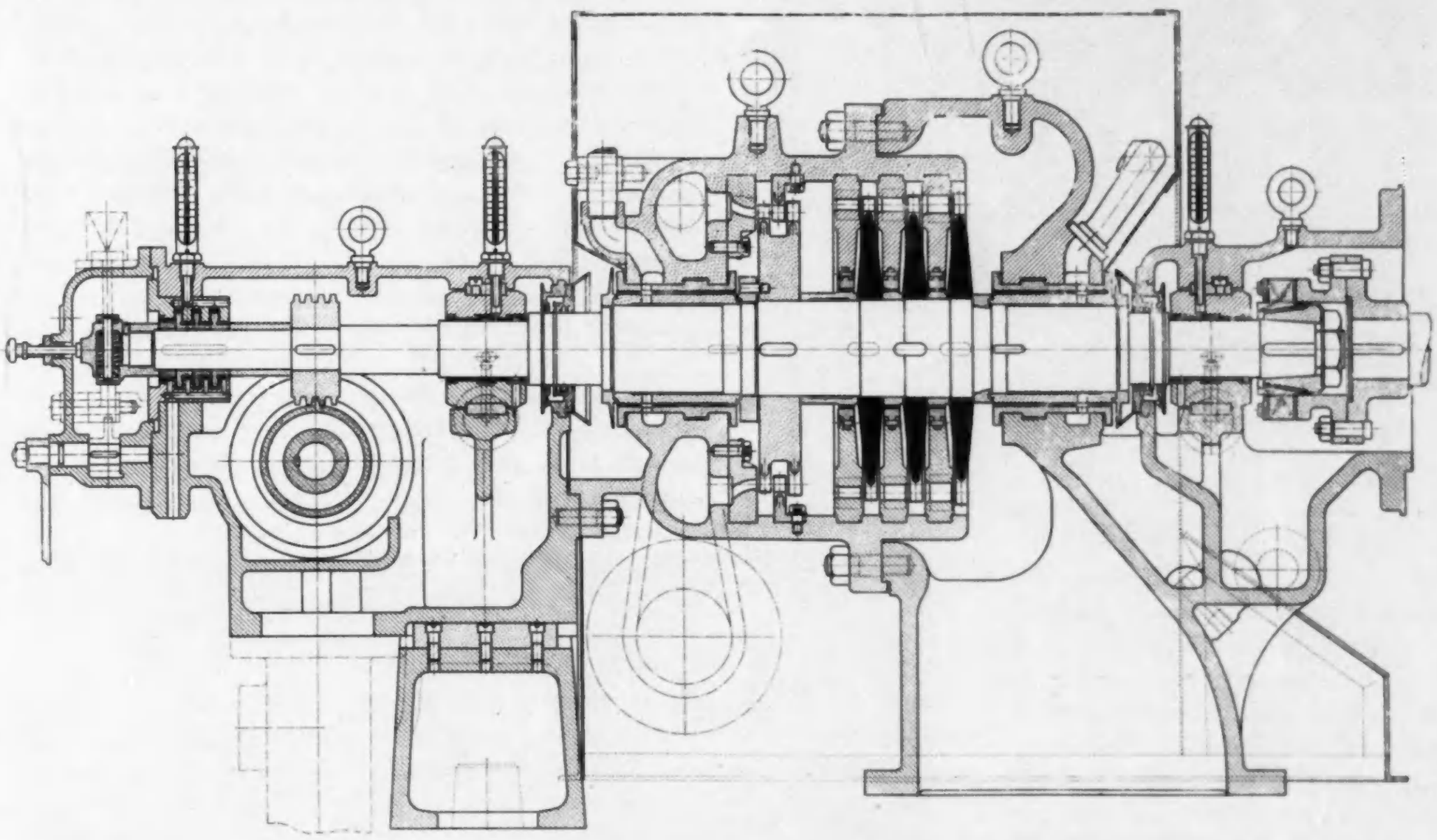

Fig. 7.—Fraser & Chalmers backpressure turbine, with several stages for outputs from 500 kW to 5,000 kW.

THE GOVERNING OF BACKPRESSURE TURBINES.

The steam admission to the turbine is controlled, as in ordinary condensing turbines, by means of governing valves. Controlling the steam quantity from no load to full load by one governing valve only, is known as throttle governing. Nozzle cut-out governing, for which more governing valves are used, consists in opening successively more nozzles in the first stage. This method, of course, is applicable only to an impulse stage. The characteristic advantage of nozzle cut-out governing is that at loads for which governing valves are provided the available heat drop is the same as at full load ; in other words, there is no throttle loss. With throttle governing, the available heat drop decreases as the load is reduced, this decrease depending on the steam conditions as can be seen from the following comparison :

Steam pressure at stop valve in lbs. per sq. in.	Steam Temp. at stop valve in degrees Fah.	Abs. pressure at Exhaust.	Percentage decrease of available heat drop when steam qty. reduced to half of full load quantity.
600	800	1" Mercury	7.2
350	750	1" Mercury	9.0
350	750	45 lbs/sq. in.	28.6

The first two cases refer to condensing turbines, the throttle loss being moderate. The last case refers to a backpressure turbine and it will be seen that the throttle loss is a very serious one. It will be realised that nozzle cut-out governing, which eliminates the throttle loss at loads for which governing valves are provided and substantially reduces it at other partial loads, possesses an extraordinarily marked

superiority over throttle governing on backpressure turbines and on all turbines working with small heat drops and fluctuating loads.

The method of operating the governing valves must fulfil two fundamental conditions:

a.—The backpressure at the turbine exhaust, within certain limits, must be the predetermined pressure necessary for the heating purposes over the whole range of load.

b.—The turbine must run at a given speed within certain small limits.

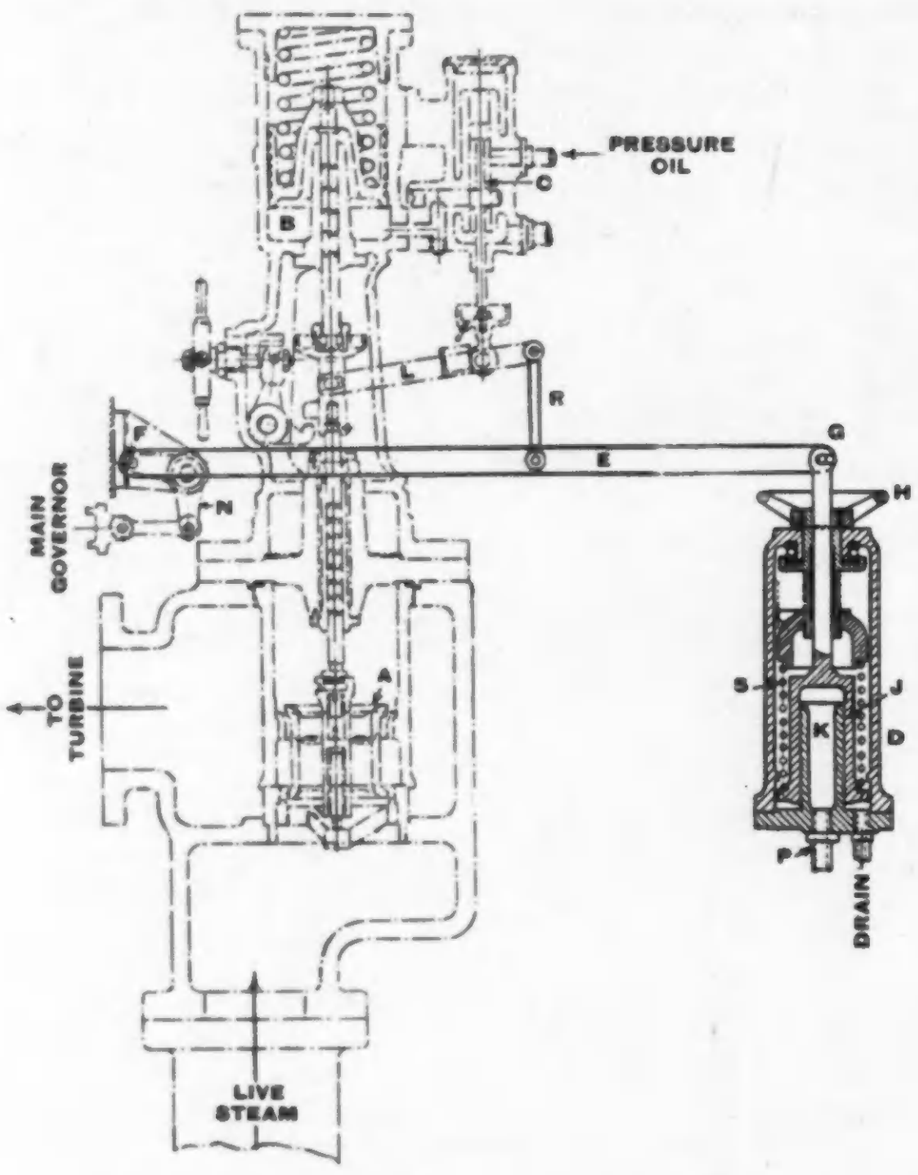

Fig. 8.—Constant pressure governor.

There are cases in which the backpressure turbine is working independently of any other power plant, and cases in which it works in parallel with other power plant. In the first case, the control is achieved by a speed governor. When the load increases the governor admits more steam to the turbine and *vice versa*. It is clear that the load determines the steam quantity available for heating. If this exhaust steam quantity is excessive, the pressure in the exhaust will rise and open a relief valve mounted on the exhaust main. The opening of the relief valve prevents unnecessary building up of backpressure, which would reduce the output and might adversely affect the process itself. (Naturally the steam blowing off through the relief valve, if large quantities are involved, may be stored in a steam accumulator from which it can be drawn when greater heating steam quantities are required, or—as happens in most cases—a passout turbine is installed instead of a backpressure turbine). If, on the other hand, the load on the backpressure turbine is such that the exhaust steam quantity does not meet the demand for heating steam, the pressure in the turbine exhaust will decrease. Between the high pressure steam main and the exhaust main, a by-pass is arranged with a reducing valve which is controlled by the pressure in the exhaust. If this pressure falls, the reducing valve admits throttled steam from the high pressure main to meet the heating steam requirements. Should this throttled steam be excessively superheated, a de-superheater may be inserted after the reducing valve.

When a back-pressure turbine operates in parallel with other plant (the latter being speed controlled) then the speed of the backpressure turbine is maintained by virtue of its parallel operation. In this case, the backpressure turbine develops all the power that can be obtained out of the heating steam, the balance of the load being taken up by the other power plant. The backpressure is maintained constant within small limits by means of a constant pressure governor. Such a governor is shown in fig. 8. The steam space "K" is connected by pipe "P" to the turbine exhaust. Under steady conditions the spring "S" balances the steam pressure (which in effect is the turbine backpressure) inside the inverted cylinder "J." Should the demand for heating steam increase, the backpressure of the turbine will tend to fall with the result that the cylinder "J" will be forced down by spring "S." Point "G" of the floating lever "E" will move downwards accordingly, likewise rod "R" and finally pilot valve "C." Pressure oil will now enter the power cylinder "B" and lift the governing valve "A," thus admitting a larger amount of live steam into the turbine until the specified backpressure and steady conditions are re-established. A decrease in the demand for heating steam will cause a reverse action. The backpressure of the turbine may be adjusted within specified limits by means of the hand wheel "H" which serves to vary the tension of the spring "S." In this way the backpressure is maintained practically constant and the output of the turbine is the total output obtainable from the quantity of heating steam.

In addition to the constant pressure governor, the turbine is provided with a speed governor adjusted to operate slightly above the normal speed. In case there is a disturbance in the paralleling mechanism, the turbine can be controlled by means of the speed governor as an emergency expedient.

It will be seen from what has been stated that whether a backpressure turbine works as an independent unit, or in parallel with other plant, the two fundamental requirements, namely, constant speed and constant backpressure, can be secured by simple means.

In fig. 9 a 600 b.h.p. 6,000 r.p.m. Fraser & Chalmers backpressure turbine for driving a rope pulley through reduction gears is shown erected on the Works test bed before delivery to a Pottery. This turbine has five stages, the first being a velocity wheel; the inlet steam pressure is 150 lbs. per sq. in. at a temperature of 550° Fah. and the backpressure 5 lbs. per sq. in.

A 450 kW 3,000 r.p.m. G.E.C.-Fraser & Chalmers backpressure turbo-alternator installed in a textile factory is shown in fig. 10. The turbine has one stage only, built as a velocity wheel and working with a steam pressure of 120 lbs. per sq in., superheat 200° Fah. and a backpressure of 25 lbs. per sq. in.

In fig. 11 is seen a 400 kW 6,000 r.p.m. G.E.C.-Fraser & Chalmers backpressure geared turbo-alternator installed in a telephone factory; the inlet steam conditions are 225 lbs. per sq. in. pressure, 600° Fah. temperature, and the backpressure is 25 lbs. per sq. in. The turbine has four stages, the first being built as a velocity wheel; it is controlled by a constant backpressure governor, the set operating in parallel with a public electricity supply.

In fig. 12 are seen two 1,000 kW 6,000 r.p.m. G.E.C.-Fraser & Chalmers backpressure geared turbo-alternators, the inlet steam pressure being 230 lbs. per sq. in., steam temperature 670° Fah. and the back-pressure 30 lbs. per sq. in. Each turbine has four stages, the first being a velocity wheel, and each supplies power and process steam for a sugar beet factory.

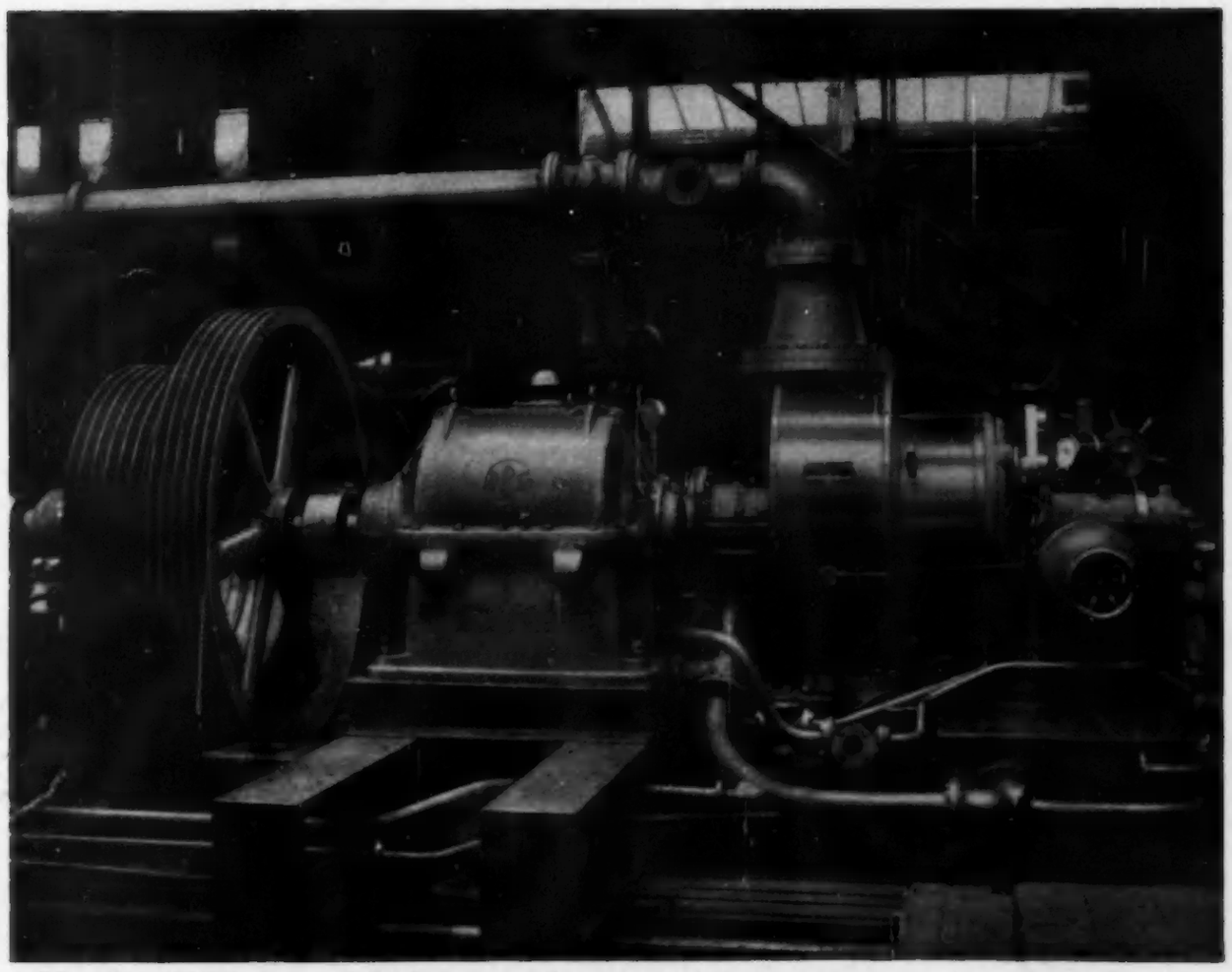

Fig. 9.—600 b.h.p., 6,000 r.p.m. Fraser & Chalmers geared turbine erected on the Works test bed.

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PASSOUT-BACKPRESSURE TURBINES.

Apart from the backpressure steam turbine there are other types of turbine which serve the double purpose of power and heating steam supply. It frequently happens that the heating steam is required at two different pressures, either for process work alone, or for process work and ordinary heating. These requirements might be met by a passout-backpressure steam turbine which is really a combination of two backpressure turbines. All the steam passes through the high pressure part, while

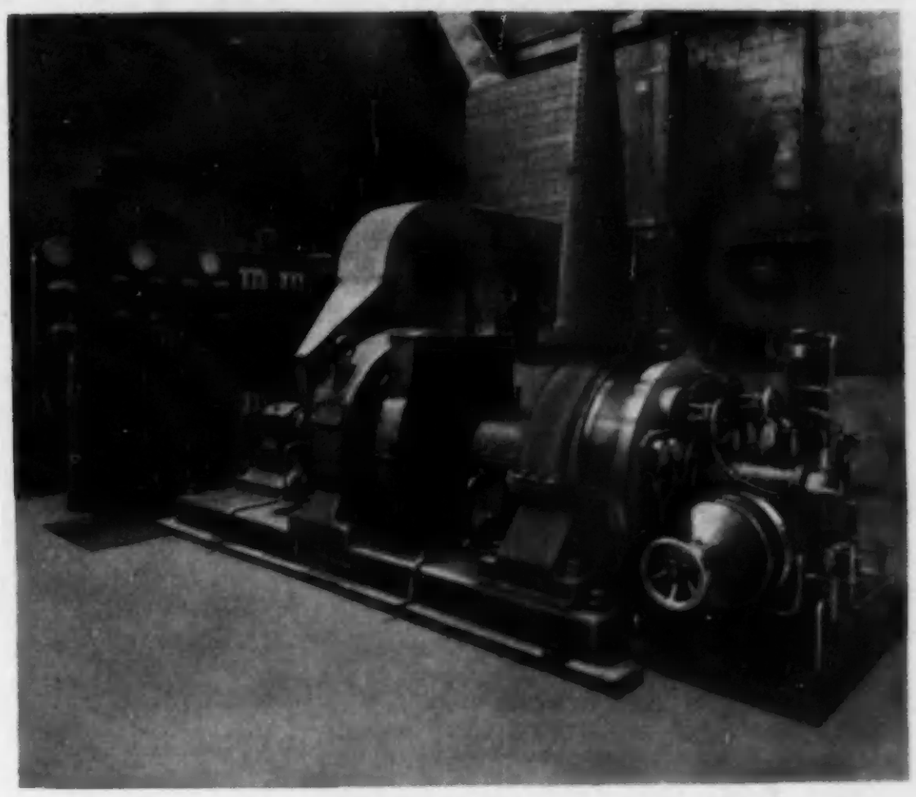

Fig. 10.—450 kW, 3,000 r.p.m. G.E.C.-Fraser & Chalmers backpressure turbo-alternator installed in a textile factory.

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at an intermediate stage of the turbine is mounted a passout main with automatic pressure regulator. Should less steam be required from this passout main, the steam pressure in it would tend to rise and the automatic pressure regulator would divert the surplus steam into the low pressure part of the turbine. The steam from the exhaust is delivered into the second steam main. The pressure in this second main is also kept practically constant by means of a second constant pressure regulator which influences the opening of the governing valves in a manner similar to the simple backpressure turbine. An example of a passout-backpressure turbine is shown in fig. 13, which illustrates a G.E.C.-Fraser & Chalmers passout-backpressure turbo-alternator having an output of 5,000 kW at a speed of 3,600 r.p.m. The inlet steam conditions are: 375 lbs. per sq. in. pressure, and 100° Fah. superheat, while the passout pressure is 150 lbs. per sq. in. (normal passout steam quantity being 25,000 lbs. per hour) and the backpressure is 15 lbs. per sq. in. Six stages are provided, the first comprising a

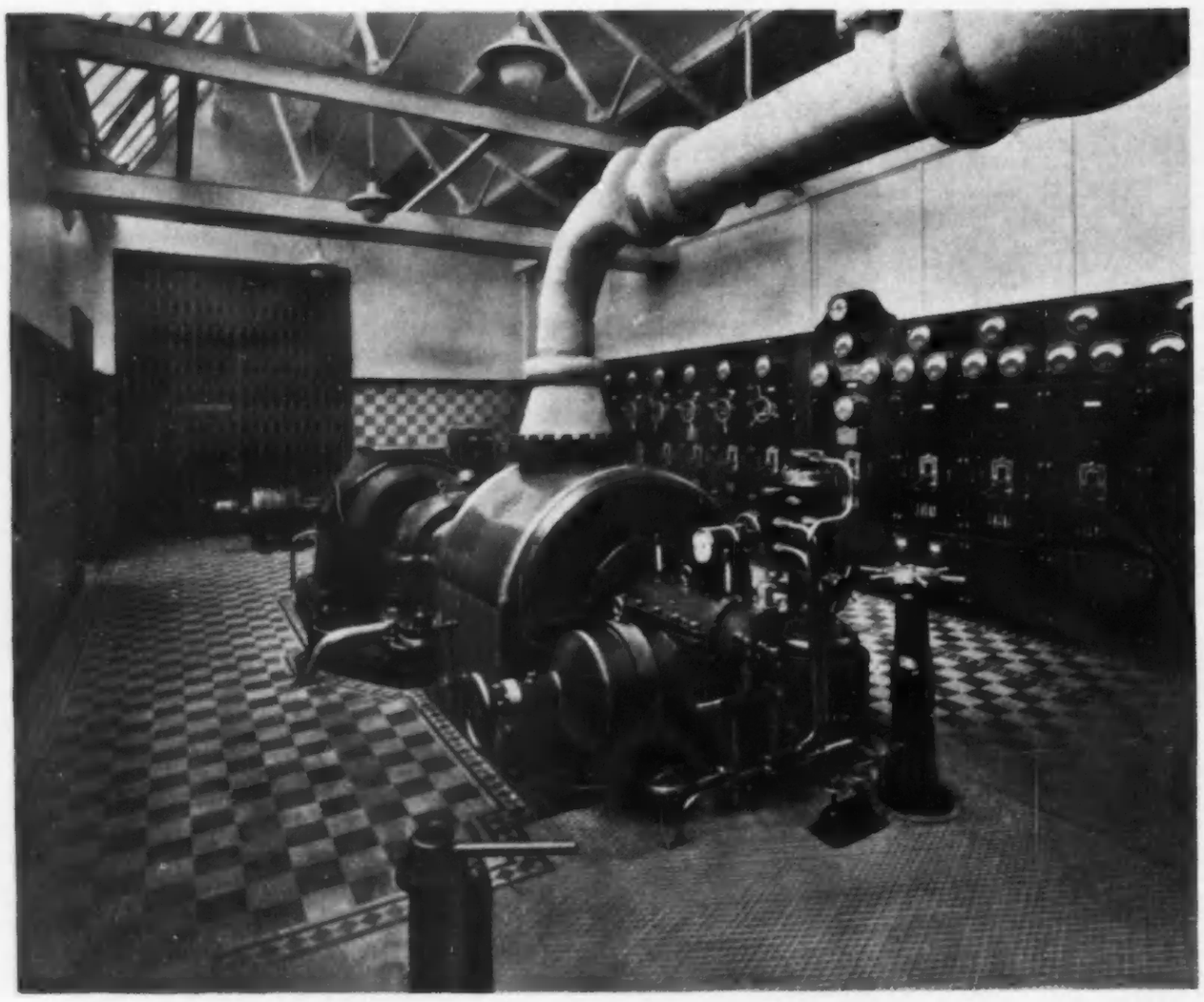


Fig. 11.—400 kW, 6,000 r.p.m. backpressure geared turbo-alternator installed in a telephone factory.

velocity wheel, immediately following which is the first passout. The set is installed in a Canadian mill and works in parallel with other plant.

PASSOUT TURBINES.

It frequently occurs that the demand for process or heating steam fluctuates within large limits. The load may also fluctuate, but the two fluctuations may not coincide. If the turbine works as an independent unit, the load may require larger steam quantities than the heating process. In such a case if a back-pressure turbine were to be used, large steam quantities would frequently have to be blown to atmosphere. To prevent this waste, a passout turbine, which is in effect a combination of a backpressure and condensing turbine, should be installed. As an example, a section through a 3,000 kW 6,000 r.p.m. Fraser & Chalmers passout turbine is shown in fig. 14. The live steam enters the turbine through a number of governing valves which successively open more nozzles. The steam works in a number of stages until it reaches the passout steam branch, at which point four sleeve valves of the balanced type are mounted inside the casing and control the steam admission to the low pressure part by successively opening groups of nozzles. The steam continues to work in the low pressure part until it reaches the condenser, which in this case is built as an integral part of the turbine exhaust.

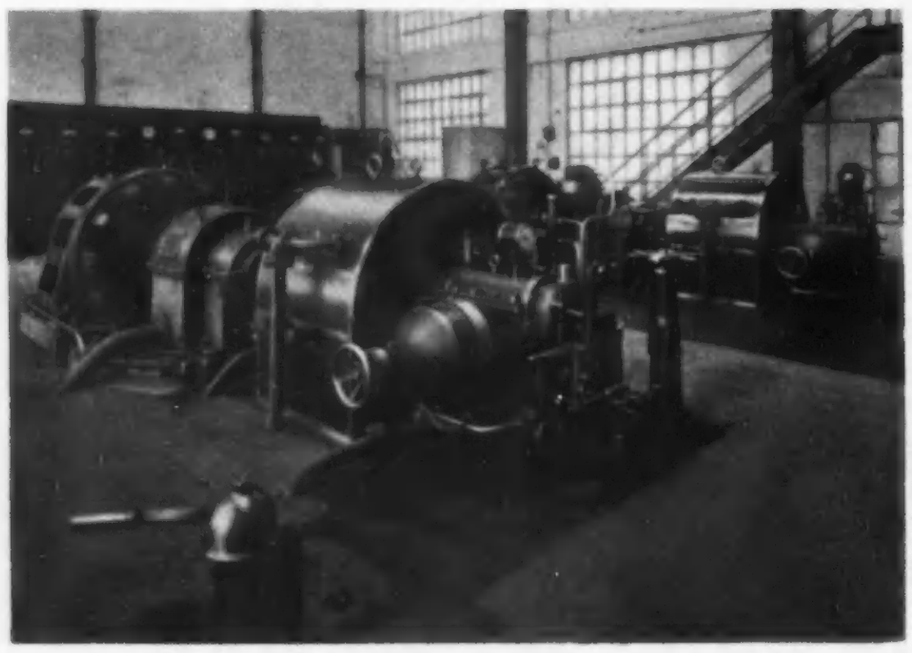


Fig. 12.—Two 1,000 kW, 6,000 r.p.m. backpressure geared turbo-alternators installed in a beet sugar factory.

The governing of passout turbines is designed to meet the following conditions:

a.—The passout steam is automatically maintained at constant pressure within very close limits over the full specified range of variation in steam quantity and load.

b.—An adjustment is provided for setting the passout pressure at a figure within predetermined limits.

c.—The speed of the turbine at constant load is not affected by varying quantities of passout steam.

This method of governing a passout turbine is shown diagrammatically in fig. 15. It will be seen that four sleeve valves "V" are mounted in the first diaphragm immediately after the passout point. Each of these valves admits steam to its own group of nozzles. All four valves are operated by a single power piston "C" and open in succession. In this manner a nozzle cut-out governing is achieved which, as previously pointed out, has a great superiority over simple throttle governing due to the comparatively small heat drop in the low pressure part of the turbine. Constant pressure at the passout branch is maintained by means of an Arca regulator "A." Should less heating steam be required, the pressure in the passout branch tends to rise; this pressure rise acts on the Arca regulator which admits oil under pressure to the power cylinder "C" the piston of which will open successively the sleeve valves "V," thus admitting more steam to the low pressure part of the turbine. Should greater steam quantity be required for heating purposes the pressure in the passout branch will tend to fall and

the Arca regulator "A," in combination with the power cylinder "C" will correspondingly close the sleeve valves "V" and so reduce the steam quantity to the low pressure part. The movement of the sleeve valves is transmitted through a train of levers to one end of a floating lever "L" the opposite end of which is connected to the spindle of the main live steam governing valve "S" and at an intermediate point the lever is actuated by the main power cylinder "P." This point is so selected that it forms a stationary fulcrum under the condition of constant load and varying passout steam quantity, thus ensuring constant speed. Should the load vary, the speed of the machine would re-act correspondingly and the speed governor would admit, through a relay, oil under pressure to the power cylinder "P," thus varying the admission of steam to the governing valves in accordance with the load.

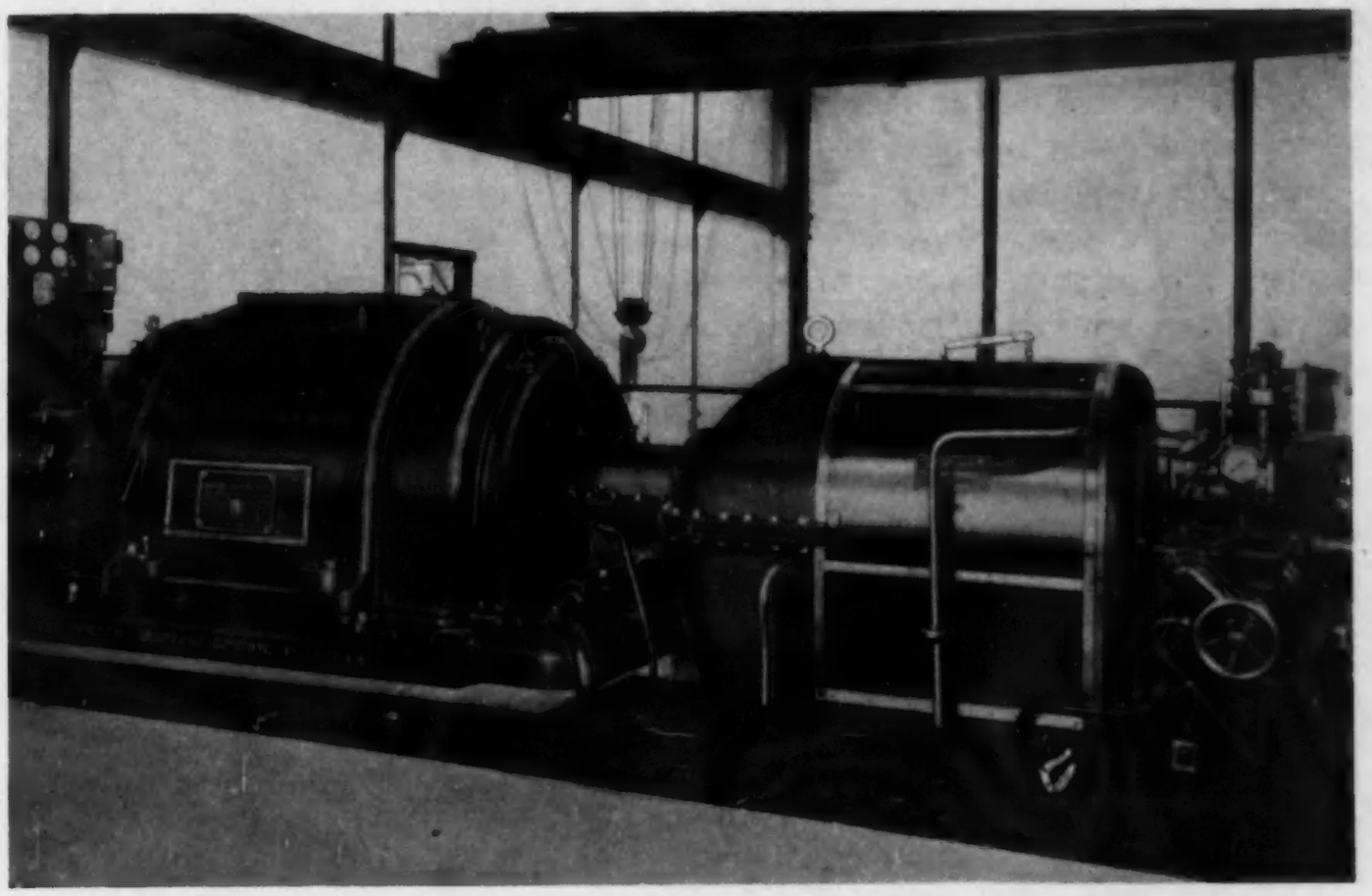


Fig. 13.—A combined passout and backpressure turbo-alternator of 5,000 kW, 3,600 r.p.m.

DOUBLE PASSOUT TURBINES.

Should heating steam be required at two different pressures, a double passout turbine is used with advantage. An example of such a turbine is shown in fig. 17. As usual the steam is admitted through a number of governing valves to the first stage. In

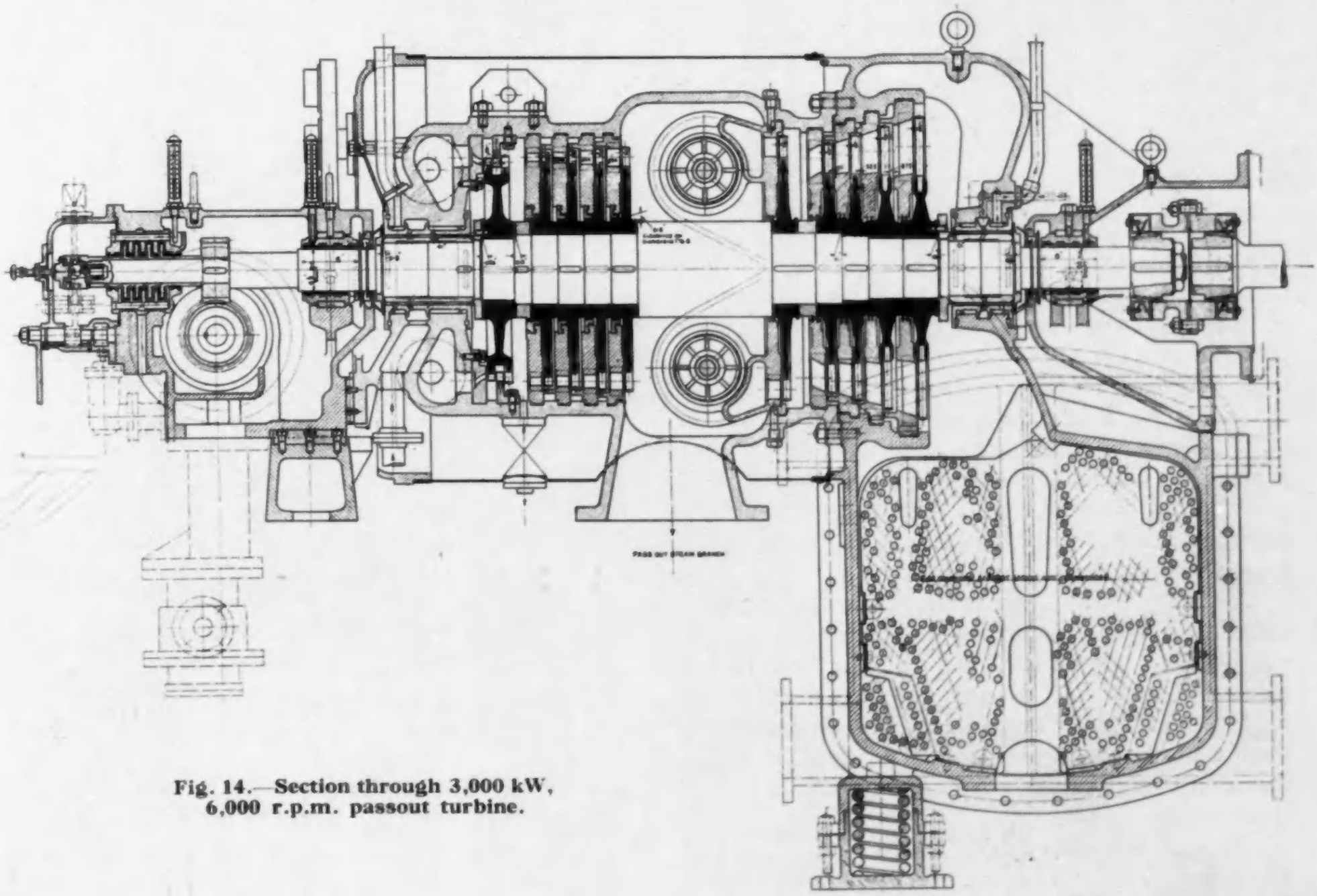
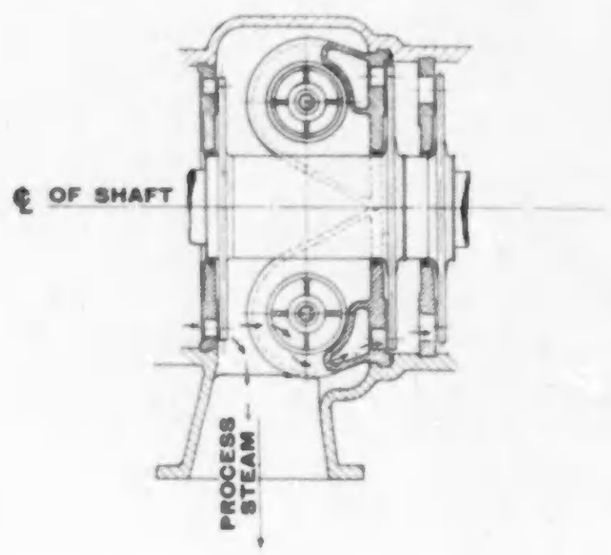
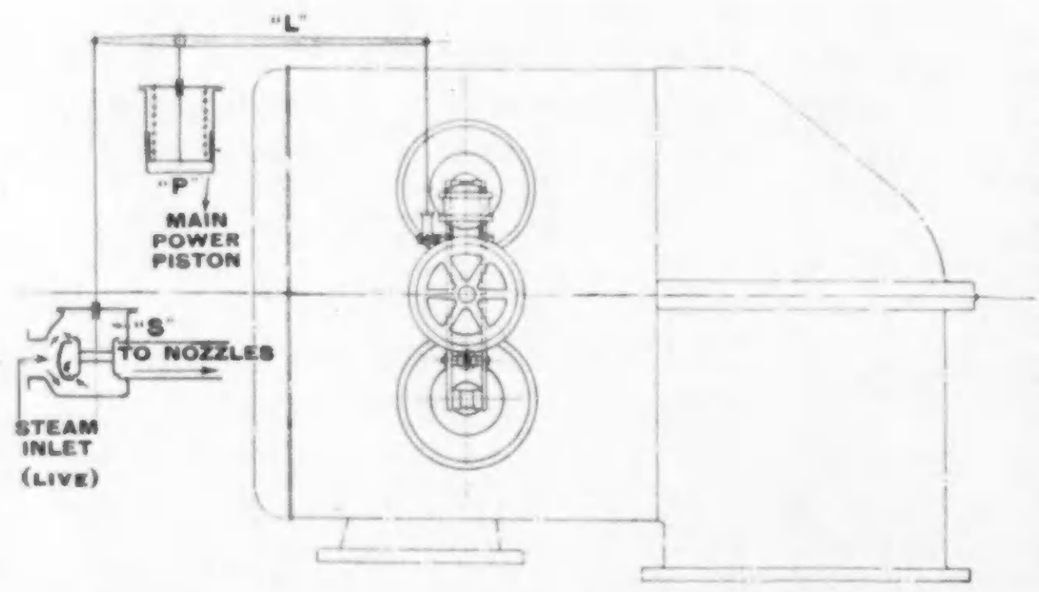


Fig. 14.—Section through 3,000 kW, 6,000 r.p.m. passout turbine.

the turbine shown, the first passout branch is immediately after the first stage. A certain amount of steam is extracted at this point, the remaining steam quantity being admitted by means of four sleeve valves to four separate nozzle groups. The steam so admitted works in four stages until it reaches the second passout branch where similar nozzle cut-out governing controls the steam admission





to the last portion of the turbine which exhausts into a condenser. The opening of the two groups of valves at the passout points is controlled by the pressure in each passout main in such a way that these pressures remain constant within small limits.

In fig. 16 is shown a 3,750 kW, 3,600 r.p.m. G.E.C.-Fraser & Chalmers passout geared turbo-generator. The inlet steam conditions are 165 lbs. per sq. in. pressure, 520° Fah. temperature, the passout pressure being 15 lbs. per sq. in. and the vacuum 28½in. (Bar. 30in.).

A group of G.E.C.-Fraser & Chalmers sets, each embodying a passout turbine is illustrated in fig. 18; two of these sets on the left hand side have each a turbine of 2,000 kW, 3,600 r.p.m., in which a first reduction gear is followed by a D.C. generator and then a second reduction gear, the wheel of which drives the mill shaft, both sets driving the mill shaft jointly.

On the right hand side is a G.E.C.-Fraser & Chalmers 5,000 kW, 3,600 r.p.m. passout geared turbo-generator, the generator being built in two units in tandem. All three turbines work with an inlet steam pressure of 165 lbs. per sq. in., steam temperature 560° Fah., the passout pressure being 18 lbs. per sq. in. and the vacuum 28in.

The largest steam turbine supplying power and heating steam installed in this country is shown in fig. 19. It is a 10,000 kW, 3,000 r.p.m. G.E.C.-

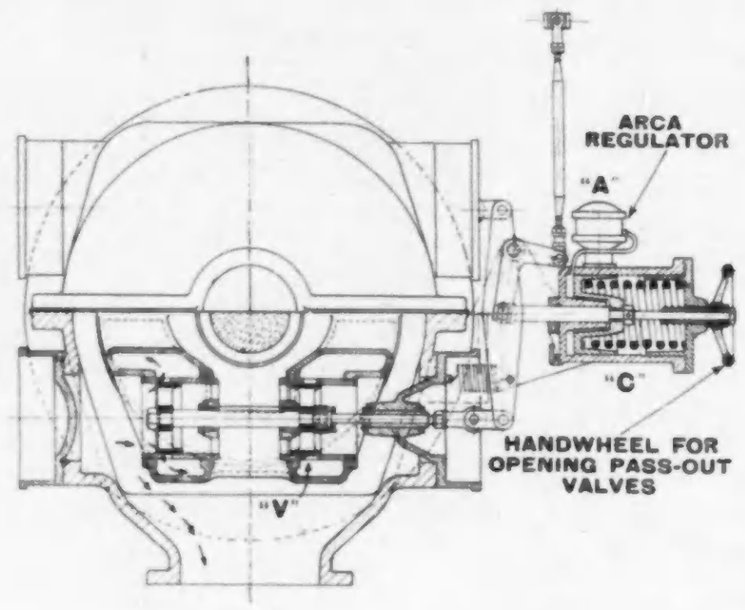


Fig. 15.—Method of governing a passout turbine.

Fraser & Chalmers double passout turbo-alternator. The turbine is built in two casings, the first having 24 stages and the second six stages. The steam pressure at the inlet is 290 lbs. per sq. in., steam temperature 650° Fah. About the middle of the first casing is provided the first passout branch, the pressure of 105 lbs. per sq. in. being maintained constant in this passout main by an automatic pressure governor which regulates the admission of steam to the following stages. The maximum passout steam quantity at this point is 130,000 lbs.

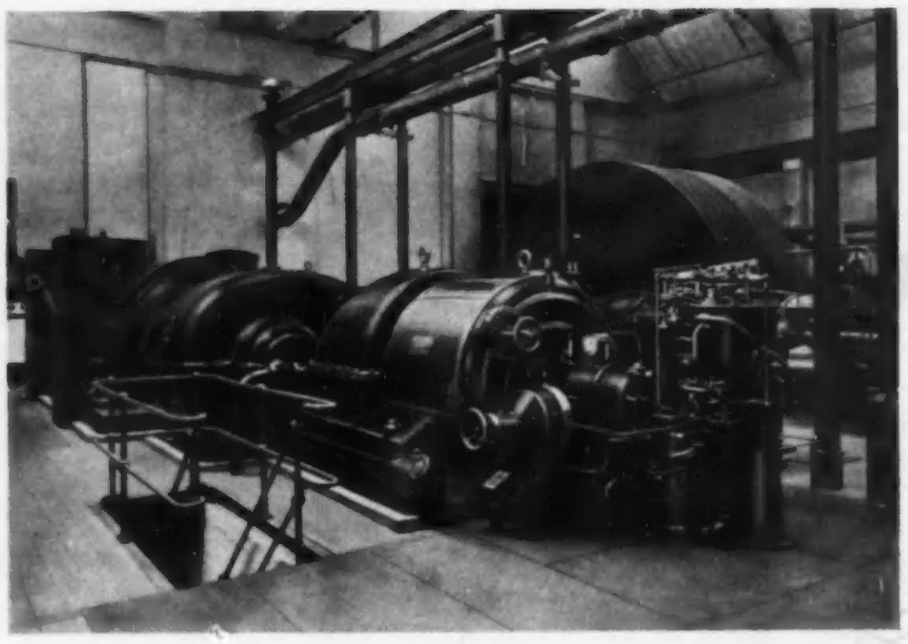


Fig. 16.—3,750 kW, 3,600 r.p.m. G.E.C.-Fraser & Chalmers passout geared turbo-generator.

per hour. In the exhaust of the first casing is provided the second passout which can supply 35,000 lbs. of steam per hour to the heating system at a pressure of 20 lbs. per sq. in., which is maintained

constant by an automatic regulator controlling the admission of the steam to the second casing. The speed of the turbine is controlled by a speed governor which operates the high pressure governing valves.

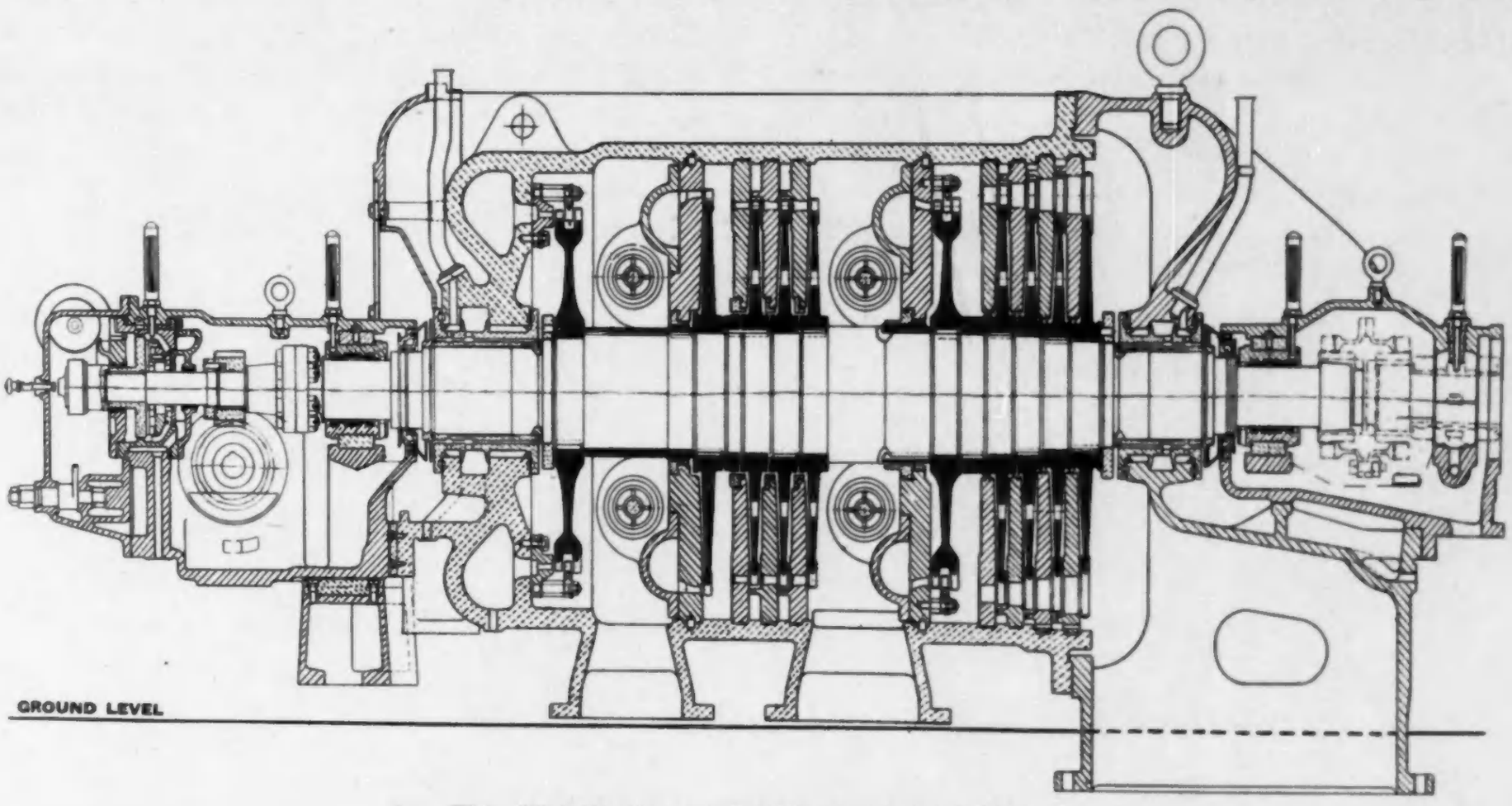


Fig. 17.—Section of double passout turbine.

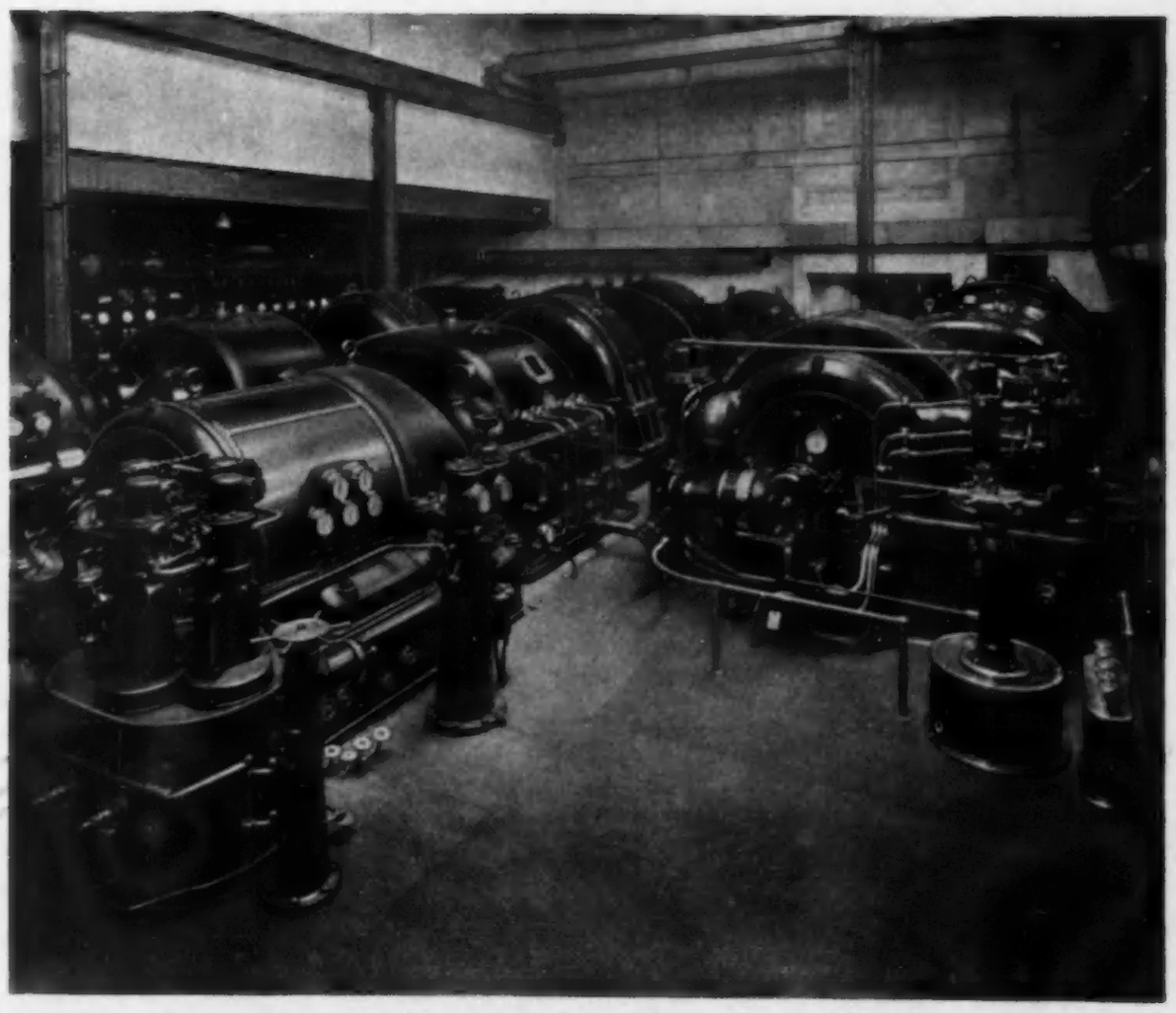


Fig. 18.—Power house of a paper mill, showing two passout turbines each driving a 2,000 kW D.C. generator and line shafting through reduction gearing; also a passout turbo-generator of 5,000 kW capacity.

CONSIDERATIONS WHEN PLANNING AN INSTALLATION.

While the economic superiority of steam turbines for the combined supply of power and heating steam over ordinary condensing turbines for power supply with separate boiler plant for heating steam is unquestioned, the planning of such plant is more complicated.

To obtain the best results, care must be exercised in determining all data bearing on the operation. If the possible economies are to be satisfactorily estimated the following particulars should be considered:

(*a*) *Fuel:* The kind of fuel, its calorific value and its price, delivered to the factory. In existing factories the yearly fuel consumption and the yearly steam consumption and power consumption.

(*b*) *Existing Boilers:* Their number, normal and maximum steaming capacity, present working pressure and temperature, present feed water temperature, present boiler efficiency or present actual evaporation per lb. of fuel of stated calorific value; the highest permissible continuous working steam pressure.

(*c*) *Live Steam Main:* Dimensions and layout of existing live steam main to the point where the turbine is to be installed. Alternatively steam pressure and temperature at this point when boilers work at the highest permissible stated steam pressure with stated normal steam quantities

(*d*) *Pressure of Heating Steam:* The lowest steam pressure required for the heating process and

its permissible variation upwards. Pressure and temperature loss in the heating steam main with stated normal heating steam quantity or alternatively layout, dimensions and particulars of insulation of this steam main.

(*f*) *Existing Power Plant :* Particulars as to kind, size and steam consumption. If outside power supply, the price per unit and the present yearly total power demand.

(*g*) *Buildings :* Particulars necessary to estimate the cost of alterations and extensions of buildings.

(*h*) *Power and Heating Steam Demand :* Normal load and simultaneous normal heating steam quantity ; diagram showing daily, weekly and seasonal fluctuations of load and heating steam quantity ; probable variation in power and steam demand as a result of probable extension or reorganisation of the factory.

Numerous industries and institutions use large quantities of steam for heating or process purposes. By installing steam turbines serving the double purpose of power supply and heating steam supply, economic advantages can be secured in the interest not only of the industries directly concerned, but of broad national prosperity.

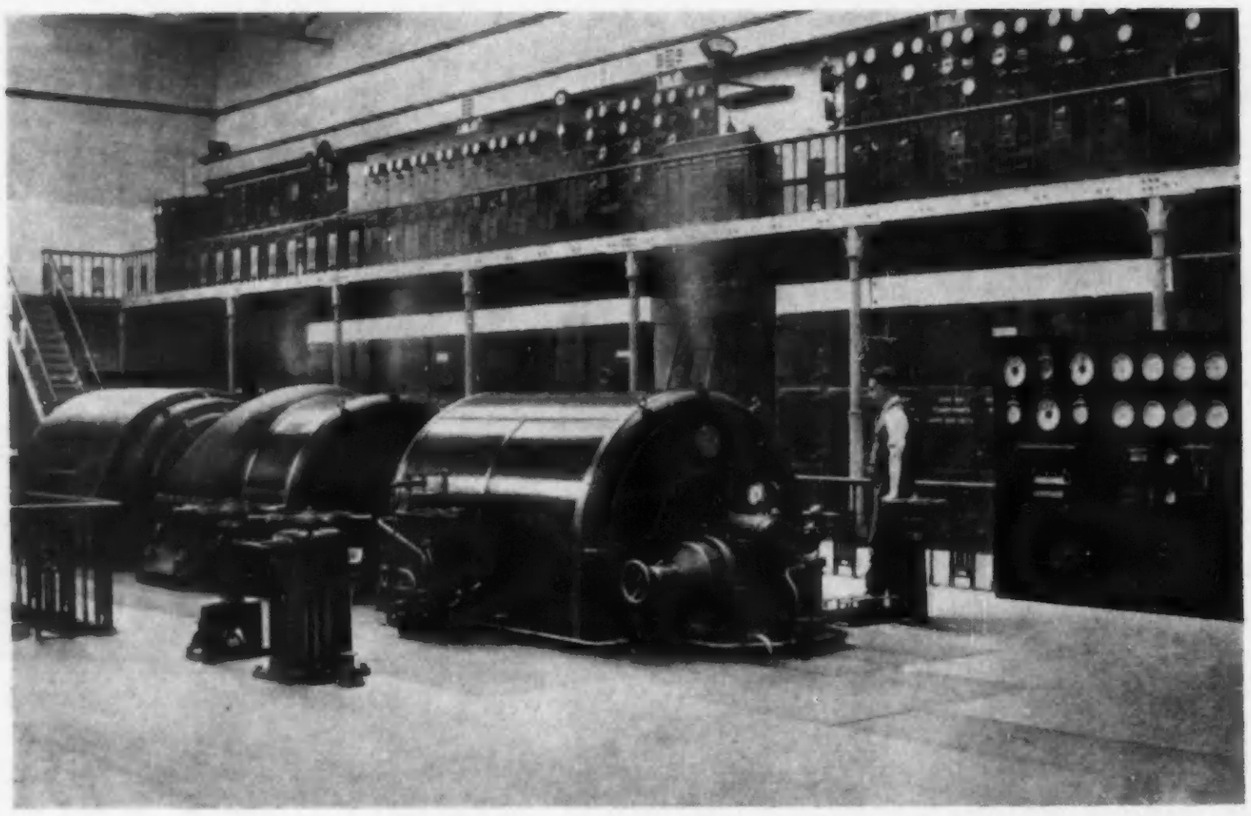


Fig. 19.—A 10,000 kW, 3,000 r.p.m. double passout turbo-alternator, the largest of its type in Great Britain installed in a paper mill.

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